

FINAL

OBJECTIVE 5
Evaluate Alternative Experimental
Strategies for Reintroducing Sockeye
Salmon to Skaha Lake

Contribution No. 13 to an *Evaluation of an Experimental Re-introduction of
Sockeye Salmon into Skaha Lake: YEAR 3 of 3*

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Executive Summary

Introduction

Historical records indicate that sockeye salmon were once found in most of the lakes in the Okanagan Basin in the Southern Interior of British Columbia. Currently, the only sockeye population within the Okanagan Basin is found in Osoyoos Lake. The abundance of this stock has declined significantly in the last fifty years, primarily due to extensive hydroelectric development in both Canada and the US, agricultural, urban and forest land use practices, restriction to sub-optimal habitats due to channel engineering, and regional impacts of climate change.

Tribes and First Nations in the U.S. and Canada have proposed re-introducing the species into Okanagan Lake, which has a large rearing capacity. Assessing the potential benefits and risks associated with a re-introduction of sockeye salmon into Okanagan Lake is difficult because of uncertainties about factors that determine production of Okanagan sockeye, and potential interactions with other species in Okanagan Lake. A 1997 workshop to discuss these issues recommended that sockeye be re-introduced to Skaha Lake as an experimental management strategy to resolve some of these uncertainties (Peters et al. 1998). For the last three years, the Skaha Lake working group (which includes representatives from the Okanagan Nation Fisheries Commission (ONFC), the Colville Confederated Tribes (CCT), the Canadian Department of Fisheries and Oceans (DFO), the B.C. Ministry of Water, Land, and Air Protection (WLAP), and ESSA Technologies Ltd.) has coordinated and conducted a research program to explore the benefits and potential risks of an experimental reintroduction of sockeye salmon to Skaha Lake.

As part of this project, ESSA has worked with the other participating agencies to develop a life-cycle model of sockeye salmon (OkSockeye; Peters and Marmorek 2003), and a framework for developing, and implementing an experimental design for the reintroduction that balances learning and conservation objectives. This framework includes sets of objectives, precautionary principles, re-introduction methods, and hypotheses, and a draft monitoring plan. We have also used the life-cycle model to evaluate relative benefits and risks associated with alternative reintroduction methods, and have conducted a preliminary set of statistical power analyses of these methods.

Objectives and Precautionary Principles

The participating agencies have defined the following set of objectives for an experimental reintroduction of sockeye salmon to Skaha Lake.

Learning: Conduct a controlled Adaptive Management (AM) experiment to evaluate what level of sockeye can co-exist with kokanee and mysids, so as to better assess risks and alternative methods of introducing sockeye to Okanagan Lake. Use the life-cycle model to help design and interpret the results of experiments.

Conservation: Establish a quasi-independent centre of sockeye production with better temperature / oxygen conditions than in Osoyoos Lake, increasing the overall resilience of the populations. At the same time, conserve Skaha Lake kokanee populations.

Increase Sockeye Production and Harvest: This is a longer term objective.

To supplement these overall objectives, the Skaha Lake working group has also defined a set of precautionary principles for how the reintroduction is carried out.

1. Collect adequate pre- and post-experimental data to evaluate impacts well.
2. Use reversible methods of sockeye reintroduction and ensure an acceptable level of impact (e.g., the loss of 1 year class of kokanee may be OK; losing 3 year classes is unacceptable).
3. Evaluate results each year and re-assess next steps.
4. Consider conservation risks to both sockeye and kokanee.
5. Recognise the need to balance the risks of acting too quickly (and making mistakes due to insufficient information) vs. the conservation risk to sockeye induced by acting too slowly.

Hypotheses to be Tested

Working group members have identified the following key hypotheses that the experimental reintroduction should address. These hypotheses represent critical uncertainties to be resolved to allow an assessment of the benefits of risks of reintroducing sockeye salmon to Skaha and (ultimately) Okanagan Lakes.

- Hypothesis 1:** Sockeye reintroduction will only cause a decline in kokanee growth / survival for certain combinations of sockeye, kokanee, and mysis densities (specific levels outlined in the report).
- Hypothesis 2:** Sockeye fry to smolt and SAR survival is as good in Skaha as it is in Osoyoos.
- Hypothesis 3:** Sockeye egg to fry survival is as good in Skaha as it is in Osoyoos.
- Hypothesis 4:** Egg to fry survival in the Okanagan River above Skaha Lake can be improved to satisfactory levels by adding gravel, reducing milfoil, and/or making channel improvements.
- Hypothesis 5:** Sockeye fry to smolt survival rates and kokanee fry to age 0 survival rates will increase if mysids are removed, with benefits to both species.

Possible Methods of Re-Introduction

The participants in this project developed three possible methods for implementing a re-introduction to Skaha Lake:

1. Remove all barriers to upstream migration, allowing adults returning to Osoyoos Lake to migrate freely to spawning locations around Skaha Lake.
2. Collect adults returning to Osoyoos Lake spawning grounds and transport them past migration barriers to spawning locations around Skaha Lake (Trap and Transport).
3. Collect female broodstock from Osoyoos Lake spawning grounds, incubate eggs in a hatchery on Skaha Lake, and release known quantities of hatchery-reared fry into Skaha Lake.

These three methods were evaluated qualitatively in terms of the three above objectives, and quantitatively using both existing literature and the OkSockeye model. The alternative methods are not

mutually exclusive, as they each address different hypotheses, and could be implemented sequentially to test a range of hypotheses. Harvesting mysis either prior to or in conjunction with the three reintroduction methods described above may improve both learning (by removing one potential confounding factor) and conservation objectives (by removing a potential competitor for food (of both kokanee and sockeye) from rearing lakes). The sequencing of mysis harvest with reintroduction is an important consideration in the overall design of the reintroduction.

Draft Monitoring Plan

The participants have jointly developed a draft monitoring plan to test out the above listed hypotheses. The plan includes monitoring of water quality, zooplankton, juvenile kokanee, juvenile sockeye, and mysids in Skaha Lake. It also includes monitoring of kokanee and sockeye spawners in the Okanagan River, as well as associated monitoring of control populations in other systems (particularly Osoyoos Lake and Wenatchee Lake, but ideally also another control for Skaha kokanee). The use of hatchery-raised, temperature-marked fry will allow an estimation of the proportion of Skaha raised sockeye that return to spawn, and their smolt to adult survival rates (SARs).

Results and Conclusions

We conducted a series of preliminary, experimental, and power analyses using the life-cycle model. In the preliminary analyses, we determined base case model settings, demonstrated that the model could reproduce the behaviour of the Osoyoos stock for reasonable parameter assumptions, illustrated the effects of natural variability on model results, explored competition effects, and answered some specific questions raised at the October 2002 workshop. We then applied what we learned from our preliminary analyses to develop a framework for the experimental analyses, where we evaluated and compared the learning and conservation implications of the three alternative introduction methods. Finally, we conducted *a priori* power analyses to further evaluate how precisely the example sockeye introduction experiments might detect the effects of sockeye reintroduction on kokanee abundance and survival. Statistical power is defined as the probability that an experiment will detect a true effect.

Results of Preliminary Analyses

- The model is able to reproduce the observed geometric mean abundance of Osoyoos Lake sockeye (around 20,000 spawners), though to do so required a relatively high SAR of 2.6%. With mysids present, the Osoyoos population is expected to gradually decline over time. For example, increasing the density of mysis from 6/m² to about 130/m² (the simulated mysis density in Osoyoos Lake after 25 years) reduces the equilibrium number of sockeye spawners from 20,000 to 6,000. A variable SAR can lead to a higher average number of spawners relative to the average with a constant SAR.
- For simulations that assumed co-occurrence of kokanee, sockeye, and mysis, we found that sockeye and kokanee abundance and survival were much more sensitive to mysis density or feeding rate than they were to each other. Mysis tends to dominate systems where they co-occur with nerkids. This points to the potential benefits of harvesting mysis.
- Skaha Lake can support 80,000 adults kokanee for particular combinations of kokanee habitat area (habitat quantity), egg-to-fry survival rate (habitat quality), and feeding rate (competitive ability). It is believed that Skaha Lake historically supported a population greater than 80,000 adults (e.g., in the late 1960s).

- Preliminary exploration of the conditions necessary to establish a sockeye stock in Skaha Lake showed that it required a combination of actions including the removal of barriers to upstream migration, the concurrent harvest of mysis in both Osoyoos and Skaha Lake, and a program to trap adults on the Osoyoos spawning grounds and transport them to Skaha Lake.

Results of Experimental Analyses

- **Hatchery fry supplementation experiment:** There was no impact to kokanee or mysis for sockeye fry stocking densities of 200/ha, which effectively quadrupled total fry densities (kokanee + sockeye fry). This is consistent with the results of the preliminary analyses. Harvesting mysis in combination with fry supplementation is beneficial for kokanee and sockeye by reducing the strong negative impact mysis competition has on their fry-to-Age 0 and fry-to-smolt survival rates. This allowed the kokanee population to increase and substantially benefited the Osoyoos stock by supplementing it with returning Skaha spawners that could not move upstream to Skaha Lake. The subsequent increase in Osoyoos fry production helped offset the steady decline of the Osoyoos stock over the simulation, more than compensating for earlier broodstock removal.
- **Trap and transport experiment:** More adults were required from the Osoyoos stock to meet the fry stocking target for this analysis than for the hatchery fry supplementation analysis (3454 vs. 385). This caused the Osoyoos stock to decline more quickly over the simulation period than under hatchery fry supplementation. There was also a small decrease in kokanee fry abundance over the treatment period, which may have been due to competition between sockeye and kokanee for spawning habitat.
- **Remove barriers experiment:** This experiment had very little effect on either the Skaha kokanee population or the Osoyoos sockeye population. This is because upstream migration conditions in the Okanagan River in most of the simulation years permitted very few spawners to migrate to Skaha Lake.

Results of Power Analyses

- Statistical power of the simple “Before-After” designs we have explored thus far are much less than the commonly applied standard of 0.8. Statistical power could be improved by reducing variation in estimates of fry abundance or survival, increasing the level of statistical significance, or including a control stock that covaried with Skaha Lake kokanee. In practice, simple experiments such as the ones we have modelled will be unlikely to attain a high level of statistical power.
- Given the low level of statistical power, the working group may wish to pursue smaller-scale experiments on kokanee/sockeye/mysis interactions (e.g. lake enclosure experiments). Such experiments, however, also create uncertainty about extrapolating those results to the larger lake system, and generally can only be run for a single season.
- In general, these example analyses suggest that a well-developed statistical design is needed to ensure that an experimental re-introduction of sockeye salmon will satisfy both learning and conservation objectives. Part of this design will require more comprehensive statistical power analyses of more complex experimental designs, more sensitive indicators of effects, more intensive monitoring programs, and further exploration of potential control stocks.

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Acronyms

O2	Oxygen
AM	Adaptive Management
ATU	Accumulated Thermal Units
AUC	Area Under the Curve
BPA	Bonneville Power Administration
CCT	Colville Confederated Tribes
CRITFC	Columbia River Intertribal Fish Commission
DFO	Fisheries and Oceans Canada
FWMT	Fish Water Management Tools
KOK	Kokanee
LLKM	Large Lakes Kokanee Model
OBTWG	Okanagan Basin Technical Working Group
ONFC	Okanagan Nation Fisheries Commission
RST	Rotary Screw Trap
SK	Sockeye
TP	Total Phosphorus
WLAP	BC Ministry of Water Land and Air Protection

1.0 Background

1.1 Overview of the Overall Project

Historical records indicate that sockeye salmon were once found in most of the lakes in the Okanagan Basin. Currently, the only sockeye population within the Okanagan Basin is found in Osoyoos Lake. Abundance of this stock has declined significantly in the last fifty years. Tribes and First Nations in the U.S. and Canada have proposed re-introducing the species into Okanagan Lake, which has a large rearing capacity. However, assessing the potential benefits and risks associated with a re-introduction of sockeye salmon into Okanagan Lake is difficult because of uncertainties about factors that determine production of Okanagan sockeye, and potential interactions with other species in Okanagan Lake.

The Okanagan Nation Fisheries Commission (ONFC) hosted a 1997 workshop to discuss these issues (Peters et al. 1998). The participants recommended that sockeye be re-introduced to Skaha Lake as an experimental management strategy to resolve some of these uncertainties. In preparation for such an experiment, the ONFC and the Colville Confederated Tribes (CCT) jointly undertook a research project to identify and assess the risks and benefits of an experimental re-introduction of sockeye salmon into Skaha Lake. This research project was funded by the Bonneville Power Administration (BPA), with the assistance of Fisheries and Oceans Canada (DFO), the BC Ministry of Water Land and Air Protection (WLAP) and the Columbia River Intertribal Fish Commission (CRITFC). ESSA Technologies Ltd. has been closely involved in both the formulation of the BPA project and the implementation of some of its objectives. The overall project has six objectives:

1. assess the risk of disease transmission from re-introduced sockeye to resident species in Skaha Lake;
2. assess the risk of accidental introduction of exotic species to Skaha and Okanagan Lakes associated with the provision of fish ladders at downstream barriers, and investigate feasible methods for reducing or eliminating these risks;
3. determine whether sockeye spawning and incubation habitat is likely to be limiting, and whether the amount of habitat can be increased;
4. develop a life-cycle model of Okanagan sockeye to project the effects of re-introduction into Skaha Lake on overall life-cycle survival of sockeye, explore potential impacts on resident kokanee, and assist in the design of an adaptive management experiment and associated monitoring program;
5. evaluate the various ways that an experimental re-introduction could be implemented, and the various monitoring programs associated with the re-introduction; and
6. finalise a plan for experimental re-introduction of sockeye salmon into Skaha Lake and associated monitoring programs.

Work on these objectives has been carried out under guidance of members of the Okanagan Basin Technical Working Group (OBTWG). Concerns about disease transmission, introduction of exotic species and habitat limitations (Objectives 1 to 3) have been addressed through field assessments (ONFC 2002). ESSA's role in this project (and the focus of this report) has been on objectives 4 and 5, which are described in more detail in the subsequent section. The ONFC and members of the OBTWG will complete Objective 6.

1.2 Objectives of Modelling Work

The overall goal of the Skaha Lake sockeye reintroduction project is to assess the possible benefits and risks of an experimental reintroduction. Potential benefits include:

- learning more about the interactions between sockeye, kokanee and mysids;
- providing an ‘insurance policy’ for the Osoyoos Lake sockeye stock by establishing a quasi-independent centre of production; and eventually; and
- increasing returns and harvest of adult sockeye as a result of opening up new spawning and rearing habitat.

Potential risks include:

- disease transmission;
- introduction of exotic species to areas that are currently inaccessible to such species;
- negative impacts on resident populations of kokanee trout through the cumulative effects of competition from introduced sockeye and mysid shrimp; and
- if survival rates in Skaha Lake are inferior to Osoyoos Lake, negative impacts on the Osoyoos stock.

A rigorous *a priori* assessment of such risks is essential for determining whether an experimental reintroduction is worth doing, and for convincing the relevant regulatory bodies that such an introduction is a safe and useful experiment. Detailed field monitoring is the most reliable way to assess the risks of diseases and exotic species, and potential spawning and rearing habitat (Objectives 1-3 of the project). Such field studies have been a major part of the project to date (ONFC 2002). However, potential risks associated with sockeye-kokanee-mysid interactions cannot be directly observed because sockeye access to Skaha Lake is currently blocked. Assessment of these risks requires addressing two important questions:

1. What range of impacts due to interaction between sockeye, kokanee, and mysids are likely to occur if sockeye are allowed to return to Skaha Lake?
2. How should we design an experimental introduction and associated monitoring so that we are able to maximise potential benefits, minimise potential risks, detect potential impacts and reduce remaining uncertainties about sockeye-kokanee-mysid interactions?

To address these questions, and meet Objectives 4 and 5 of the overall project, ESSA developed and applied a life-cycle model for Skaha Lake sockeye, kokanee and mysid populations, as well as for Osoyoos Lake sockeye and mysid populations. Over the last year, this work has been undertaken through an iterative, interactive process with close involvement of all agencies (Table 1-1). This report is a continuing part of that process.

Table 1-1: Process of model development and application.

Period	Progress Made
Dec/2001– Feb/2002	Development of a draft design document by ESSA
Feb/2002	Review and revision of the draft design by scientists from ONFC, DFO, WLAP, and CCT at a <i>Design Review Workshop</i> at the ONFC
April 2002	Distribution of a substantially revised design document in, together with a spreadsheet version of the sockeye-kokanee-mysid competition submodel
June 2002	Distribution of Version 1.0.0 of the model, including submodels and a User Interface written in VisualBasic, an ACCESS database for all input data and parameters, and Excel spreadsheets for displaying the results of model runs
Sept-Oct/2002	Preliminary model testing and sensitivity analyses
Oct 2002	Demonstration and review of the model at a <i>Hypothesis Workshop</i> , attended by scientists from ONFC, DFO, WALP, and CCT. This meeting served also to identify and begin to evaluate alternative methods of sockeye reintroduction and associated monitoring
Nov-Dec 2002	Development of a list of action items from the workshop (Appendix A); substantial modifications to the model based on recommendations from the <i>Hypothesis Workshop</i> ; model analyses to assess alternative methods of re-introduction and the implications of different combinations of sockeye, kokanee and mysids.
Dec-Jan 2003	Compilation of a draft of this report, in preparation for a report/model review and model training workshop on Jan 14-15 th , 2003.
January 2003	Held a two-day workshop to review the draft report, review the model assumptions and outputs, and provide training on how to use the model to conduct analyses
Jan-Feb 2003	Finalisation of report and model.
February 2003	Distribution of Version 2.2 of the life-cycle model (including a revised design document and user's guide), and a Draft version of this report
May 2003	Distribution of the Final Version of this report.

1.3 Structure of this Report

This report summarises the results of discussions at the *Hypothesis Workshop* and subsequent data and simulation analyses that address the two key questions outlined above.

The remainder of this report presents:

- a review of the objectives of the re-introduction, precautionary principles agreed to by the group, and a qualitative evaluation of alternative methods of re-introduction, based on workshop discussions (Section 2);
- an overview of the proposed monitoring plan (Section 3);
- an evaluation of risks and benefits using available literature¹ (Section 4);
- a quantitative evaluation of risks and benefits using the model (Section 4);

¹ The literature synthesis is awaiting material from Kim Hyatt – see Appendix A.

- a demonstration of how to use the life cycle model to evaluate alternative methods of re-introduction (Section 4); and
- Conclusions and Recommendations (Section 5).

The content of the report includes:

- new information, concerns and objectives raised by workshop participants at the October 2002 *Hypothesis Workshop*;
- new data provided by OBTWG members subsequent to the October 14-15 workshop (see Appendix A for a listing of what information has been received to date);
- an evaluation of competition hypotheses using this new information and the results of model analyses;
- calibration of the model to ensure that it can reproduce the general level of sockeye abundance observed in Osoyoos Lake, and the general level of kokanee abundance of Skaha Lake (both historic and current levels); and
- model analyses of experimental alternatives using the life-cycle model (version 2.2).

1.4 Next Steps

This report concludes ESSA's work on the BPA contract. However, this work should feed into a set of future steps to be carried out by the ONFC and OBTWG, which were discussed at the *Hypothesis Workshop* in October 2002 and the model/report review meeting in January 2003:

- development of a Technical Implementation Plan proposal by the ONFC and CCT, with participation of OBTWG scientists;
- development of an Implementation Agreement by policy personnel in ONFC, CCT, WLAP, DFO and any other relevant agencies (e.g., Transplant Committee);
- application for funding (to BPA and possibly other agencies) for the Adaptive Management (AM) experiment to re-introduce sockeye to Skaha Lake;
- implementation of the AM experiment, including field monitoring, data analysis to test hypotheses and model improvements; and
- evaluation of the results of the AM experiment (Figure 1-1).

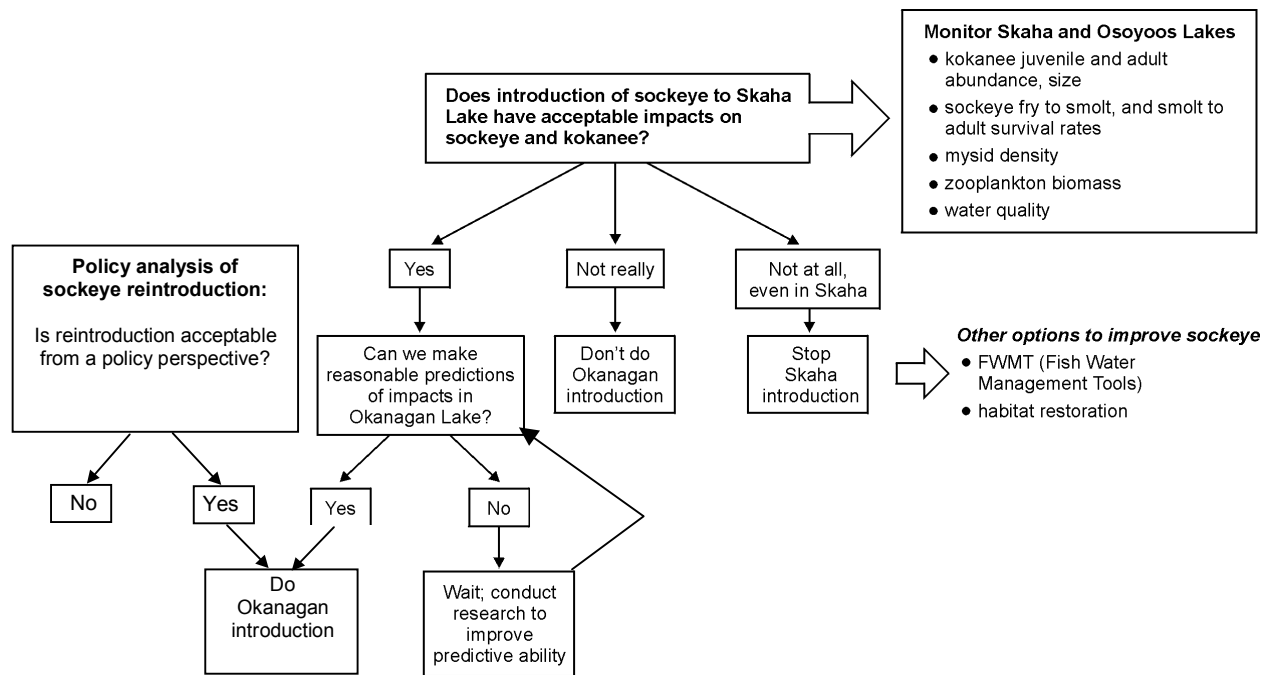


Figure 1.1: Possible outcomes of sockeye re-introduction to Skaha Lake, and possible decisions arising from alternative outcomes (based on discussions at workshops in October 2002 and January 2003).

2.0 Alternative Methods of Re-introduction

2.1 Objectives of Skaha Lake Reintroduction

At the October 15th-17th 2002 *Hypothesis Workshop*, the ONFC, WLAP, and DFO representatives agreed on the following objectives for the reintroduction:

- **Learning:** Conduct a controlled Adaptive Management experiment to evaluate what level of sockeye can co-exist with kokanee and mysids, so as to better assess risks and alternative methods of introducing sockeye to Okanagan Lake. Use the life-cycle model to help design and interpret the results of experiments.
- **Conservation:** Establish a quasi-independent centre of sockeye production with better temperature / oxygen conditions than in Osoyoos Lake, increasing the overall resilience of the populations. Maintain existing Osoyoos population, given potential changes in climate and other environmental factors. At the same time, conserve Skaha Lake kokanee populations.
- **Increase Sockeye Production and Harvest:** This is a longer term objective.

The participants noted that the current objectives now differ somewhat from the original objectives considered at the 1997 workshop (Peters et al. 1998). In particular, the emphasis on conservation of sockeye has increased because of increases in the abundance of *Mysis* in Osoyoos Lake in recent years, and a deterioration of lake oxygen/temperature conditions suitable for sockeye rearing (Kim Hyatt, DFO, pers. comm.). These changes are expected to decrease the survival rates of Osoyoos Lake sockeye over the fry-to-smolt life stages, placing them at greater risk of extinction, and increasing the benefit of having a quasi- independent centre of sockeye production. Ultimately the critical issue for sockeye is whether the abundance and resilience of the Okanagan stock are increased or decreased as a result of the Skaha Lake re-introduction.

In general, monitoring the impacts on fry to smolt (sockeye) or fry to age 0 (kokanee) survival rates are related to learning objectives, while monitoring the impacts on adult sockeye and kokanee spawners are related to conservation and harvest objectives.

Concerns about sockeye should not supplant the need to also protect and conserve kokanee populations in Skaha Lake (Steve Matthews, WLAP, pers. Comm). Kokanee populations have generally been at low levels of abundance in Skaha Lake, and have been negatively impacted by habitat loss and mysid populations. Bearing in mind the multiple objectives of conserving both sockeye and kokanee, as well as learning more about competitive interactions, the group specified a set of precautionary principles to help guide the development and assessment of reintroduction methods (Box 2.1).

Box 2.1: Precautionary principles for guiding the development and evaluation of experimental sockeye reintroduction methods for Skaha Lake:

1. Collect adequate pre- and post-experimental data to evaluate impacts well.
2. Use reversible methods of sockeye reintroduction and ensure an acceptable level of impact (e.g., the loss of 1 year class of kokanee may be OK; losing 3 year classes is unacceptable).
3. Evaluate results each year and re-assess next steps.
4. Consider conservation risks to both sockeye and kokanee.
5. Recognise the need to balance the risks of acting too quickly (and making mistakes due to insufficient information) vs. the conservation risk to sockeye induced by acting too slowly.

Point #5 in Box 2.1 is a common tradeoff in adaptive management experiments (Walters and Green 1997). Longer experiments provide more precise testing of alternative hypotheses, but delay taking actions that may be required to meet ecological and socioeconomic objectives. Shorter experiments lead to faster long term decisions, but have a greater risk of error. This tradeoff exists for the issue of sockeye reintroductions to Skaha Lake. In particular, the years 2003 to 2005 are likely to have a large number of sockeye returning off of the 2000 brood year, which provides an ideal opportunity to re-introduce sockeye to Skaha Lake with a relatively small impact on the Osoyoos stock. On the other hand, having more years of baseline data would provide a stronger ability to evaluate the results of the experiment.

2.2 Possible Methods of Reintroduction

The OBTWG discussed three general methods of reintroduction at the October 15–17th workshop:

- removing all barriers to upstream migration of sockeye spawners from Osoyoos lake to Skaha Lake;
- trapping adult sockeye spawners below McIntyre Dam and transporting them to Skaha Lake; and
- trapping adult sockeye females below McIntyre Dam, incubating their eggs in a hatchery, and releasing fry to Skaha Lake.

Each of these methods is discussed below, and evaluated qualitatively against the three objectives listed in Section 2.1. This evaluation synthesises discussions at the *Hypothesis Workshop*. More detailed evaluations using available literature and the model are included in Section 4.

2.2.1 Remove all Barriers

This is the most direct and intuitively ‘natural’ method for reintroduction. Anecdotal information (observations of spawners at McIntyre Dam by native fishers and the dam operator) suggest that the early part of the Osoyoos sockeye run (July) will move upstream and spawn if the barriers are removed. There is however some uncertainty concerning the nature of early arrivals at McIntyre Dam. Some people consider the early arriving fish to represent the vestigial remnants of an historical Okanagan Lake sockeye run. Others believe that the arrival time at McIntyre dam is a function of temperature conditions in the Columbia.

Conservation:

Risk to Osoyoos sockeye: This method could place the Osoyoos stock at higher risk in two ways. First, natural migration could lead to lower net production from the Osoyoos stock. Returning adults tend to move as far upstream as temperature and time to spawning permit (Kim Hyatt, pers. comm.). This means they may not make it all the way to Skaha Lake and end up spawning in habitat that is of lower quality than what is currently available below McIntyre dam. In addition, migration from upstream spawning and rearing areas may also expose smolts to higher predation risk during migration (e.g., passage through Vaseaux Lake, a risk faced with all three methods of reintroduction). These factors could together lead to a lower rate of sockeye production from Skaha Lake than from Osoyoos Lake, which would lower overall sockeye production from the Okanagan Basin. Second, this is a passive method that relies on nature to generate the conditions that would allow sockeye to reach Skaha Lake, conditions which may not occur before rearing conditions in Osoyoos Lake deteriorate to the point where the Osoyoos stock is lost. These risks would make it difficult for DFO to justify just opening the barrier to upstream migration.

Risk to kokanee: Relatively few sockeye spawners are likely to reach Skaha Lake. Therefore the risk to Skaha lake kokanee from competition with sockeye is likely to be low. Sensitivity analyses using the life cycle model can illustrate the range of conditions under which competition with sockeye fry will become important. In general, these simulations show the kokanee population to be quite resilient to competition with sockeye, but affected more significantly by competition with mysids, which are already present in relatively high densities in Skaha Lake (Section 4.1.2).

Reversibility: This method is conceptually easy to reverse, as it would only require re-creating impassable barriers at McIntyre Dam. The cost of reversing this action depends on how it is implemented. It would be least costly to leave McIntyre dam in place, and selectively allow sockeye through the dam. This action would be easy to reverse, and would also prevent movement of any exotic species. Conversely, removing the dam entirely would require more time and money to reverse the action (i.e., construct a new barrier).

Learning:

The rate of learning about the strength of competition will be a function of the natural variability in fry abundance, measurement error associated with estimating fry abundance, the annual contrast in treatments (i.e., sockeye fry abundance), the degree of control over the number of fry introduced to the lake, and the sequence of introduction (e.g., high-low-high, etc). The passive nature of the “remove barriers” method will have a slow rate of learning because natural variability in fry abundance will be high (creating an inconsistent ‘treatment’), and sampling for sockeye fry abundance will add measurement error. The number of spawners returning to the lake (and, consequently, the number of sockeye fry introduced to Skaha Lake) will be a function of conditions beyond the control of researchers, such as survival rates in the Columbia River hydrosystem and ocean. However, the natural migration method will also provide information on the spatial distribution and habitat usage of sockeye spawners returning to the upper portion of the Okanagan River, which the other methods would not.

Increase sockeye production and harvest:

This method has the potential to directly address this long-term objective since sockeye will be free to establish in Skaha Lake. Because this method allows for natural migration behaviour, it would allow for natural selection and could therefore reduce the genetic risks associated with more artificial approaches to reintroducing sockeye to Skaha Lake. However, it could take a relatively long time before sockeye production from Skaha Lake is large enough to allow increased harvest.

2.2.2 Trap and Transport (Truck, or Lift)

For this method, sockeye spawners would be collected below McIntyre Dam, transported to Skaha Lake, and then released to spawn.

Conservation:

Risk to sockeye: There may be less risk to sockeye than in the “remove barriers” option because fish would only be collected when returns of Osoyoos Lake spawners are high. Fish could also be trucked to a preferred spawning location, reducing the risk of spawning in suboptimal habitats. Risks will also depend on the direct and indirect effects of trapping and transporting fish (e.g., increased stress could increase egg retention and lower overall egg production). These effects could be minimised by only collecting spawners in relatively good condition (e.g., collect earliest returning spawners, which will have shorter holding times in the Okanagan and Columbia Rivers).

Risk to kokanee: The risk to kokanee depends on how many sockeye are introduced, and the abundance of mysids (Section 4.1.2). Since this option could potentially introduce higher numbers of sockeye to Skaha Lake, it could result in a greater level of competition on the spawning grounds and in the lake than the “remove barriers” option. However, if kokanee production is carefully monitored, then negative effects on kokanee could trigger a halt in the trap and truck experiment.

Reversibility: This approach is easy to reverse; just stop collecting and transporting.

Learning:

This is a less passive method than “remove barriers” and thus provides the opportunity for an increased rate of learning. Because a known number of spawners would be introduced to Skaha Lake, there would be potentially better estimates of spawning success, the natural egg-to-fry survival rate, and the opportunity to observe sockeye spawning habitat selection.

However, the adult take will still be dependent on the condition of the Osoyoos stock and egg-to-fry survival will be dependent on natural conditions. Thus Skaha Lake sockeye fry production will still be highly variable, and sockeye fry abundance estimates will be uncertain. This means a relatively poor experimental control over the number of fry added to Skaha Lake to test competition hypotheses.

Increase sockeye production and harvest:

This method may cause a net increase in production of Okanagan sockeye, if Skaha spawners have higher spawner to spawner survival rates than Osoyoos spawners. However, returning progeny of Skaha spawners will be stopped by McIntyre Dam. Assuming that Skaha spawners will spawn and rear in habitats currently occupied by Osoyoos spawners and juveniles, this could increase intra-species competition for spawning and rearing habitat. Given temperature/oxygen constraints on rearing habitat in Osoyoos Lake, these competitive effects could be significant. The objective of increased production will only be fully achieved when barriers are removed and high spawner to smolt survival is established in Skaha Lake.

2.2.3 Egg Incubation and Fry Introduction Experiment

This method involves taking adults from the Osoyoos stock, then incubating their eggs to the fry stage in an existing hatchery adjacent to Skaha Lake. Thermal shock treatment is used to mark fry otoliths, the fry are then released to Skaha Lake in precisely known numbers. All barriers to upstream migration remain

in place. The overall method is described below in Box 2.2; example calculations of the number of adults required to produce particular fry density targets are provided in Section 4.4.

Box 2.2: A general structure for the fry incubation experimental introduction method.

Method:

- take about 200 to 300 returning sockeye females in late September / early October from below McIntyre Dam {bio-sampling already being done there for the FWMT project};
- fertilise and incubate eggs in Skaha Lake hatchery (may need to cool groundwater so that eggs don't hatch too soon; use FWMT model to get appropriate ATUs);
- place desired number of fry in Skaha Lake in spring;
- this general structure can accommodate different specific patterns of introduction. For example, the applying the same treatment 5 years in a row; varying treatments in 3-year blocks, concurrent harvesting of mysis, etc).

Conservation:

Risk to sockeye: Because a much higher egg-to-fry survival rate can be achieved in a hatchery setting than under natural conditions (e.g., 70% hatchery vs. approximately 10-20% natural), far fewer adults need to be taken from the Osoyoos stock to provide fry for Skaha Lake than the trap-and-truck method. Though this method would provide greater numbers of fry for a given number of adults than the “remove barriers” or “truck and transport” method, it could still be constrained by the number of available adults from the Osoyoos stock in years when adult returns are particularly low. Because barriers to upstream migration (McIntyre Dam) would be retained, returning adult progeny of fry stocked in Skaha Lake, and their progeny, would increase the density of spawners and juveniles using existing spawning and rearing habitat in and around Osoyoos Lake. These potential competitive effects, particularly in habitat-limited Osoyoos Lake, would have to be considered when deciding how many fry to release into Skaha Lake.

Reliance on artificial propagation could cause potential harmful genetic risks to both the Osoyoos and Skaha populations. For example, if the female broodstock removed from the Osoyoos stock was relatively genetically homogenous, this would result in a Skaha population that lacked the genetic diversity necessary to persist in variable environmental conditions. Genetic matching protocols would be necessary to ensure that genetic diversity in the Osoyoos broodstock was representative of the population as a whole.

Risk to kokanee: There would be no risk to kokanee from competition on the spawning ground because no adults would be released. With barriers in place, no adults will return. However, there is a potentially greater risk to kokanee fry and age 0 juveniles from competition than the trap-and-truck method because larger numbers of sockeye fry could be introduced. Kokanee populations will still need to be monitored to ensure that there are no deleterious impacts. One workshop participant raised the question of whether there was some potential for sockeye residualization (i.e., sockeye becoming kokanee), and whether this would be considered a genetic contamination of the Skaha kokanee stock. The converse situation (potential smoltification of kokanee juveniles) could pose similar risks to the sockeye stock. More information on the genetic differences between the two populations is needed to determine the importance of these potential risks.

Reversibility: This method is highly reversible, just stop introducing fry. Any residualization would dissipate over time, and the natural spawning kokanee would re-establish dominance.

Learning:

This method provides much greater flexibility and control over the number of fry introduced to the lake and the opportunity for greater contrast in competitive pressure. An additional advantage is that the number of fry introduced to Skaha Lake will be known precisely. The greater contrast in numbers introduced and greater precision in fry abundance estimates will allow more precise and timely estimation of competition effects.

Higher numbers of marked fish will allow improved detection of Skaha Lake smolts at Wells Dam (note however that smolts are currently not monitored at Wells Dam). This will provide the opportunity for better estimates of smolt production from Skaha Lake and better assessment of Osoyoos-Skaha differences in smolt to adult survival rates. If smolts are also monitored at McIntyre Dam, this approach would also provide a means of estimating predation rates between Skaha Lake and McIntyre Dam.

This method alone will not provide information on spawning habitat selection and quality, or spawning success. However such information could be gained through ancillary field work (e.g., use in-stream incubation boxes for data on *in situ* sockeye egg-to-fry survival rates (an index of spawning habitat quality); radio tagging/tracking of a few introduced adults to track habitat selection and behaviour, and competition for spawning sites between sockeye and kokanee).

Increase sockeye production and harvest:

This method would not directly address this objective in the near term, but would be a first step in a long-term reintroduction process. Although adults produced from the Skaha fry would return to McIntyre Dam, the full reintroduction process would not be complete until barriers were removed. If this method and other ancillary field work provides evidence that satisfactory egg to smolt survival rates could be achieved for sockeye in Skaha Lake without harming kokanee, then the next logical experiment could be a trap and truck experiment (Section 2.2.2), which if successful could in turn lead to removal of barriers (Section 2.2.1).

2.3 Considerations for an Overall Experimental Design

Because the three reintroduction methods address slightly different hypotheses, they are not mutually exclusive. One may want to perform these experiments in sequence so as to test alternative hypotheses sequentially in a logical and unconfounded manner. For example, one approach would be to implement the fry incubation and release strategy first to test hypotheses about interactions between sockeye fry, kokanee fry, and mysid shrimp. Next, the trap and truck approach could be implemented to test hypotheses about the quality and quantity of spawning habitat available around Skaha Lake. Finally, one could implement the remove barriers approach to test hypotheses about the effects of migration conditions in the Okanagan River on the spatial distribution of sockeye spawners between Osoyoos and Skaha Lake spawning areas.

Another consideration in the overall experimental design is the effects of mysis on sockeye and kokanee survival and growth rates. A mysid harvest experiment is currently being implemented in Okanagan Lake (Andrusak et al. 2002), which could be extended to Skaha and perhaps Osoyoos Lakes. Harvesting mysis in conjunction with the three reintroduction methods described above may improve both learning (by removing one potential confounding factor) and conservation objectives (by removing a potential

competitor for food from rearing lakes). Participants at the January 2003 workshop discussed two alternative strategies for implementing mysis harvest. One option would be to implement an experimental mysis harvest before implementing sockeye reintroduction. This would provide key information on mysis-nerkid interactions without introducing the costs and potential risks associated with sockeye reintroduction. However, such an approach would not be as appealing to various entities (e.g. ONA, DFO, BPA) primarily interested in sockeye, not kokanee, conservation and enhancement. The other approach would be implement mysis harvest and sockeye reintroduction concurrently. This approach would allow a more immediate assessment of hypotheses about sockeye-kokanee interactions and about relative fry survival rates in Skaha and Osoyoos Lakes, although such assessments may be complicated by the concurrent removal of mysis. It is a tradeoff between conservation and learning objectives. Simultaneously harvesting mysis and re-introducing sockeye helps sockeye conservation sooner, but sacrifices some clarity in learning because of changing two things at once.

3.0 Overview of the Proposed Monitoring Plan

This section summarises the baseline data required for assessing our ability to detect effects of interest during experimental reintroduction, the hypotheses that monitoring plans should be designed to address, and the components of those monitoring plans and model analyses used to explore some components of experimental introductions (e.g., simulated fry introductions).

3.1 Baseline Information Required to Detect Impacts of Reintroduction on Other Ecosystem Components

Baseline information (or “Before treatment” data) is necessary to empirically detect and assess changes in survival and growth rates due to competition. A list of information needs was compiled at the October 2002 *Hypothesis Workshop*, and is summarised in Appendix A. The information below represents all of the information that has been received by February 11th, 2003.

Existing data for Skaha Lake include:

- mean size-at-age for Age 0, 1, 2, 3, 4 kokanee. (We have some data for Skaha Lake from Steve Matthews that provides rough estimates of Age 0, 1, 2, and 3 lengths);
- estimates of the within and between year variation in age-specific sizes;
- existing survival estimates of year classes of kokanee plus any new information from recent sampling;
- 15 years of kokanee spawning abundance and distribution (rough estimates received from Steve Matthews);
- five years of juvenile kokanee abundance estimates (Kim Hyatt);
- five years of mysis density estimates (Kim Hyatt);
- zooplankton abundance and species composition (Vic Jenson; Kim since 1997) – (Kim Hyatt and Howie Wright); and
- ancillary explanatory variables: TP, O2, temperature (Howie Wright).

Participants at the January 2003 review meeting pointed out that the large number of Skaha kokanee spawning in the fall of 2002 (around 100,000 spawners, which represents a 10-fold increase over recent abundances) provides a unique opportunity to collect data under high density conditions. These data could be used to test hypotheses about potential limiting factors for this population, or for testing the ability of current monitoring methods to detect large changes in abundance. For example, the acoustic trawl survey data of juvenile kokanee densities in Skaha Lake in the next few years should show a large pulse of juvenile density resulting from this year’s large escapement. It will be critical to continue to monitor for such effects as part of the baseline monitoring described above.

3.2 Hypotheses to be Tested

The monitoring should be able to provide tests of the following hypotheses (from the October 15th-17th *Hypothesis Workshop*).

Hypothesis 1: Sockeye reintroduction will only cause a decline in kokanee growth / survival for certain combinations of sockeye, kokanee, and mysids densities.

Alternative Hypothesis 1A: Increased sockeye returns will increase nutrient concentrations and improve kokanee growth in a subsequent year.²

Hypothesis 2: Sockeye fry to smolt and SAR survival is as good in Skaha as it is in Osoyoos.

Hypothesis 3: Sockeye egg to fry survival is as good in Skaha as it is in Osoyoos.

We could develop more explicit versions of Hypothesis 1 to test using the “pie slicing” assumptions of the life-cycle model and simulating the effects on kokanee of a variety of feasible combinations of sockeye and mysids in Skaha Lake. The model can be used to simulate different experiments and output key performance measures that reflect variables which would be measured in the field, with simulated measurement error included, to assess our ability to detect impacts of varying magnitude.

There are also some “mitigation hypotheses” of interest:

Hypothesis 4: Egg to fry survival in the Okanagan River above Skaha Lake can be improved to satisfactory levels by adding gravel, reducing milfoil, and/or making channel improvements.

Hypothesis 5: Sockeye fry to smolt survival rates and kokanee fry to age 0 survival rates will increase if mysids are removed, with benefits to both species.

Alternative Hypothesis 5A: Removal of mysids will reduce growth of older age kokanee, neutralising the benefits of higher egg to age 0 survival rates.

Hypothesis 6: Early-returning adults that come back to McIntyre Dam and then fall back to Osoyoos Lake experience lower pre-spawning survival than later-returning fish because they have to spend a longer time exposed to increased temperature stress in Osoyoos Lake. Early-returning adults which were allowed to pass by McIntyre Dam would experience higher pre-spawning survival.

3.3 What to Measure: Where, When, Precision

The final implementation plan needs to address a number of monitoring questions:

- What components of the system are of interest or concern (e.g., sockeye egg-fry survival, kokanee survival)?
- What attributes of the system should be measured to address these interests and concerns (e.g., fry abundance, smolt abundance, fry size, smolt size, etc.)?

² Information to test this hypothesis may be available from Quesnel Lake, as well as from an ONFC literature review by Adrian Vedan, and a reference from the Bureau of Commercial Fisheries, Donaldson and Kern (Howard Smith to provide). Skaha Lake may already have sufficient TP, such that additional contributions from sockeye would not significantly change productivity.

- When should these attributes be measured and how often (e.g., spring, summer, fall; weekly or monthly)?
- How should the attribute be measured (e.g., sonar, rotary screw traps, trawl)?
- What is the expected precision based on historical information for the selected method (e.g., range of variation for fry abundance estimates using method X)?
- What is the desired precision (e.g., to provide statistical power of 80%)?
- Can the desired precision be achieved, given our assumptions about natural (uncontrollable) variability? (see Section 4.1.2)

The group addressed these questions to some extent during the October workshop, as summarised under the three headings below.

3.3.1 Skaha Lake Monitoring

Monitoring would include:

- three acoustic/trawl surveys (lake is small enough to survey the entire area): May, late fall / early winter; late Jan-Feb (pre-smolts, used as estimate of smolts);
- precision of acoustic surveys is estimated to be about $\pm 40\%$ ($\pm 20\%$ with greater effort)}. More precise methods are possible (e.g., mark-recapture) but the increased precision may not merit the increased cost, and the change in methods from those used to collect baseline data may limit the usefulness of the data for illustrating before/after changes;
- O_2 and Temperature (weekly to biweekly during the Aug-Oct critical period for temperature / oxygen squeeze in Osoyoos Lake; can do monthly at other times); Total Phosphorus (TP) (weekly to monthly now in BPA project (more intensive in Osoyoos); spring and fall by WLAP);
- zooplankton (biweekly from Feb/April to June to catch cladoceran bloom and see if mysids delay it; monthly during July–November); save samples, analyse if necessary. Look at whether emergence time of KOK affects their survival due to hitting or missing bloom; and
- size at age information for kokanee (scale samples, otoliths).

3.3.2 Okanagan River Monitoring

Monitoring would include:

- smolt biosampling at McIntyre Dam (for length and timing);
- possible Vaseaux Lake predation study with tagging at Okanagan Falls and recovery at McIntyre Dam with RST;
- otolith samples from spawners to assess % of Skaha-origin vs. Osoyoos-origin, age distribution, sex distribution.(with the hatchery experiment, smolts could be temperature marked with an external mark as well)
- intensified escapement monitoring and biosampling of kokanee (AUC, daily or every second day, in a boat); and
- continued monitoring of sockeye escapement using current methods.
- boat counts of smolts in April in Osoyoos Lake staging area

3.3.3 Columbia River Monitoring

Monitoring would include:

- returning spawner count at Wells Dam $\{\pm 10\%$; include in observation submodel}, Zosel? (BPA proposal);
- smolt counts at Wells or Zosel (would need to be externally marked to distinguish between Skaha and Osoyoos-origin smolts);
- smolt counts at Rocky Reach (Kim Hyatt is talking to Chelan PUD about collecting 100–200 smolts for biosampling); and
- use PIT-tags to estimate survival rates in Okanagan River (between Skaha and Osoyoos lakes) and in Columbia River (Kim Hyatt will be talking to the Mid-Columbia Coordinating Committee).

3.3.4 Control Populations

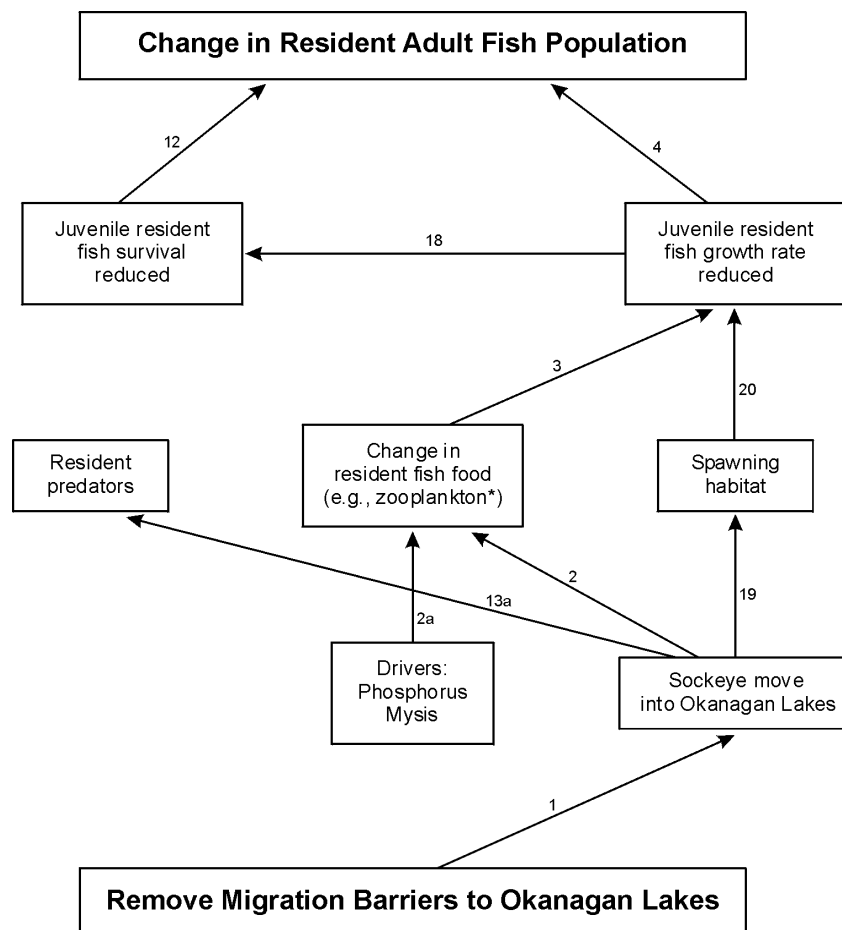
Control populations help to ensure that observed changes are not due to regional climatic factors, and can in fact be attributed to actions that affect freshwater habitat. For kokanee, it is important to continue to monitor Okanagan Lake and other nearby populations (e.g., Kalamalka Lake), although Steve Matthews noted that there are no long-term kokanee monitoring for lakes other than Okanagan, and that there are major differences in chemistry between Skaha and Okanagan lakes. There is a “Catch 22” with respect to the issue of finding control populations for kokanee. There are only weak correlations of spawner abundance between Skaha and other nearby lakes, which implies that these other lakes would not be good control populations (see Section 4.5.3). However, these correlations may be weak simply because of inadequate monitoring methods with substantial measurement error. Thus we don’t have a strong rationale for monitoring control lakes precisely for kokanee until we monitor them more precisely to establish a higher correlation with Skaha. Catch 22!

For Skaha sockeye, it is important to continue to monitor Barkley Sound (for variations in large-scale ocean climate factors), Osoyoos sockeye (to control for local climatic and flow effects) and Wenatchee stocks (to control for Columbia River factors such as Columbia River flow, which would affect both upstream and downstream migration conditions. The Washington Department of Fish and Wildlife monitors Wenatchee abundance.

4.0 Results: Evaluation of Risks and Benefits / Refinement of Experimental Design

4.1 Overview of Impact Hypotheses

At the 1997 workshop, participants reviewed a number of hypotheses related to the potential impacts of sockeye re-introductions (Peters et al. 1998). Many of these hypotheses (e.g., effects of disease and exotics, availability of spawning habitat) have been addressed by other reports (ONFC 2002). Figure 4-1 and Table 4-1 shows a subset of some of the original hypotheses reviewed at the initial workshop. The key links of interest here are numbers 2, 2a, 3, and 18, which are best considered jointly. Section 4.1.1 evaluates these hypotheses based on existing literature; Section 4.1.2 evaluates them using the model.



*zooplankton represented implicitly in model, not explicitly

Figure 4-1: Revised impact hypothesis diagram from the October 15–17 workshop. These links will be explicitly evaluated in this report. The other links originally shown in Figure 4.7 of the 1997 workshop report are being addressed in other research projects.

Table 4-1: Descriptions of Impact Hypotheses for links shown in Figure 4-1.

Link	Link Description
1	Once migration barriers have been removed, anadromous sockeye will continue their upstream migration, entering Vaseaux Lake, Skaha Lake, and eventually Okanagan Lake.
2	Once inside the Okanagan lakes, anadromous sockeye will compete with resident fish for food organisms, such as zooplankton, thereby effectively reducing the abundance of available food.
2a	Concentrations of phosphorus and <i>Mysis</i> are the two main “drivers” influencing species composition and abundance within the Okanagan Lake zooplankton community.
3	A reduction in food abundance will reduce growth rates for resident fish.
4	Reduced growth rates for resident fish will lead to decreased numbers and biomass of adult populations of these fish species.
12	Reduced survival rates for resident fish will lead to decreased numbers and biomass of adult populations of these fish species.
13a	Re-introduction of sockeye will provide another prey source for resident predators.
18	Reducing growth rates in juvenile resident fish could cause reduced survival of these fish.
19	Once anadromous sockeye adults arrive at Vaseaux, Skaha, and Okanagan lakes, they will seek spawning habitats in either lakeshore or river / tributary stream environments.
20	Competition for spawning sites could result in reduced growth rates for juvenile resident fish.

4.2 Results of Literature Review

Synoptic observations from lake-to-lake comparisons can be very informative. At the workshop, Kim Hyatt provided a verbal summary of competition between kokanee and sockeye (quantitative data on TP levels and species abundances from different lakes were unavailable for this report). In low productivity coastal lakes with TP < 5 ug/l, sockeye outcompete kokanee. Sockeye have larger eggs, which provide an energetic advantage, particularly in years with a late plankton bloom. In these lakes, older age classes of kokanee have difficulty finding food. In interior lakes with greater productivity (TP > 10 ug/l), sockeye and kokanee are able to co-exist (e.g. Quesnel, Horsefly, Shuswap). For lakes with a TP of 5 to 10 ug/l, the outcome of competition is “a toss-up”. TP estimates for Osoyoos and Skaha Lakes are shown in Figure 4-2. TP in both lakes has declined since 1990. Recent values of TP suggest that coexistence of sockeye and kokanee is likely in Osoyoos Lake (TP around 15 ug/l), but less certain in Skaha Lake (TP around 10 ug/l).

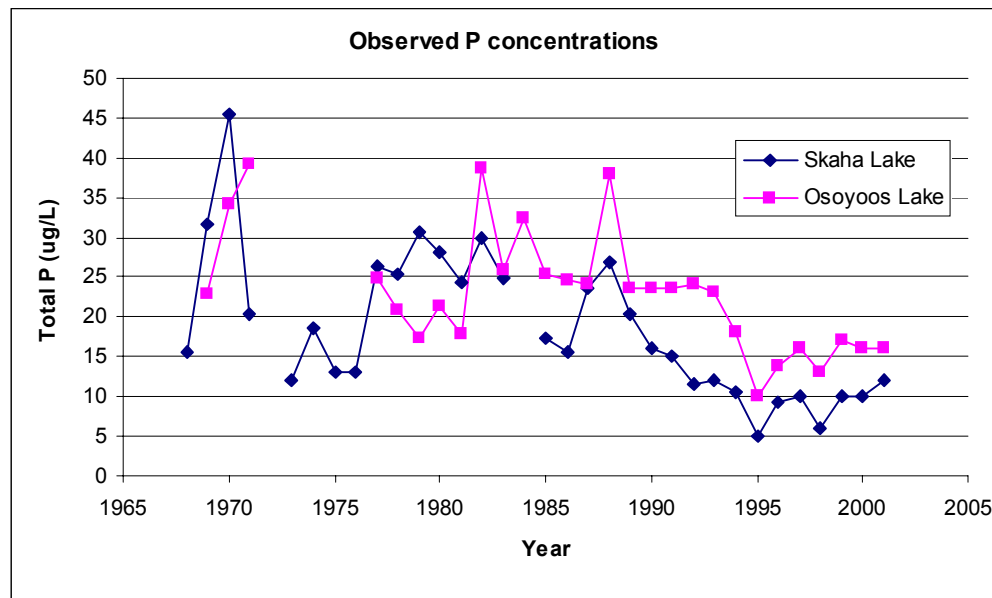


Figure 4-2: Total Phosphorus concentrations in Osoyoos and Skaha Lakes, 1968-2001. Data provided by G. Huggins, WLAP.

Lake-to-lake comparisons can also provide insights on the ability of nerkids and mysids to co-exist, and can form the basis for hypothesising about the factors that determine whether co-existence is likely (Table 4-1a). For example, in Wood Lake, mysids have yet to establish despite high productivity (>15 ug/L of total phosphorus). One reason for this may be the relative shallowness of the lake, which limits the amount of vertical refuge for mysids from kokanee predation. Another interesting example is Kalamalka Lake, where mysids have established at relatively high densities while kokanee populations have remained stable. This lake is of average depth and productivity, although it is not as shallow as other lakes where kokanee are declining. This suggests that something other than productivity and depth may be the primary factor for allowing mysids and kokanee to coexist in this lake. Possibilities include higher alkalinity of Kalamalka Lake, and differences in emergence timing in Kalamalka Lake such that kokanee fry enter the lake after mysid densities peak. In Lake Tahoe, mysid densities are high but kokanee are stable, perhaps because cultural eutrophication provides enough nutrients to allow co-existence.

While such comparisons are informative, there are many confounding factors that need to be considered when drawing conclusions. Other factors in addition to mysids have played a role in kokanee population declines in virtually all of the lakes in which such declines have been observed. For example, Lake Pend Oreille has very high mysid densities, but other factors such as predation, hatcheries, and dams have also affected kokanee populations. Changes in habitat conditions have played a role in many of the lakes listed in Table 4-1a. Trends in lake productivity have also likely affected observed patterns in kokanee populations. Increasing eutrophication in the Arrow Lakes and Kootenay Lake, and increasing oligotrophication in Okanagan lake, have likely influenced the relative balance between kokanee and mysid populations. Such factors make it difficult to ascribe observed declines in kokanee populations directly to mysids. Still, a more in-depth assessment and comparison of the physical and biological information in lakes with different species compositions would be a useful approach for further exploration of nerkid-mysid interactions.

Table 4-1a: Preliminary synopsis of Kokanee Lakes with *Mysis relicta* (compiled by Howie Wright, ONFC).

Lake	Study Years	Physical Properties						Chemical Properties	Mysis relicta		Kokanee depressed	Other Factors for Decline (y/n)	Ref. (2)	Comments
		Trophic Status (1)	Trend	Mean depth (m)	Max Depth (m)	Lake residency (years)	Surface Area (km ²)	TP (ug/L)	Year Introduced	Current Density (no./m ²)				
Wood		M	Stable	22	34	30	9.3	> 15	1960s?	-	n	y	1	some stream habitat degradation, water flow issues
Kalamalka	1996-1998	O	Stable	59	142	65	25.9	5 to 15	1960s?	418	n		1,2,3	stream habitat loss, water flow
Okanagan	1996-1998	O	Oligo-troph	76	242	60	348	8	1966	300	y	y	1,3,4	stream habitat loss, water flow
Skaha	2001, 2002	O-M	Stable	26	57	1.2	20.1	12 (2001); 8 (2002)	1966-1972	130 (2001); 83 (2002)	y	y	1,5	stream habitat loss and water flow, River channelization
Osoyoos (North Basin only)	2001, 2002	M	Stable	21	63	0.7	9.91	22	after 1992	50 (2001); 93 (2002)	y	y	1,5,6	stream habitat loss and water flow, River channelization
Upper Arrow	1997-present	O	Fertiliz.	101	287	<1	275	3 to 5	1968 and 1974	32 (1997); 71 (1998)	y	y	7,8,9, 10	dam construction, impoundment, loss of trib habitat, fert has resulted in larger mysids with increased fecundity with no increase in density
Lower Arrow	1997-present	O	Fertiliz.	57	194	<1	190	3 to 5	1968 and 1974	63 (1997); 99 (1998)	y	y	7,8,9, 10	dam construction, impoundment, loss of trib habitat
Slocan	2000-2001	O	Stable	171	298	7	69	4.6	1973	111	y	n	11	thought to be in decline, little knowledge though
Kootenay	1993-present	O	Fertiliz.	94	154	1.5	390	5 to 10	1949 and 1950	98-288	y	y	12,13	dam construction, impoundment, loss of trib habitat, nutrient loading that lead to overfishing, then oligotrophication
Pend Oreille	19	O	Cultural eutroph	164	351	3.2	383	assume <10	1966-1970, 1 st sampled 1972	2148	y	y	14,15	popular sport fishery from 1940s - 1970s. Lake trout predation, hatchery supplemented and mysis introduction
Flathead	1986	O-M	Cultural eutroph	32.5	113	3.4	510	5.9 (2000)	1 st detected 1981	peaked at 130, now b/w 16 and 68	y	y	16	kokanee introduced in 1916, initial decline in 1970s due to hydroelectric development with persistence of fishery (200,000 fish/yr), declining rapidly since 1985

Lake	Study Years	Physical Properties						Chemical Properties	Mysis relicta		Kokanee depressed	Other Factors for Decline (y/n)	Ref. (2)	Comments
		Trophic Status (1)	Trend	Mean depth (m)	Max Depth (m)	Lake residency (years)	Surface Area (km ²)	TP (ug/L)	Year Introduced	Current Density (no./m ²)				
Tahoe	1966-1991	O	Cultural eutroph	313	505	700	501	6.3 (1992)	1963 to 1965	>300 in 1970 (peaked and most likely lower now)	n	n	17,18	Kokanee introduced (1940s) prior to mysid introduction, documented collapse of cladocerans due to mysid and kokanee cropping. Affected kokanee size of spawning but not numbers. Clouded by cultural eutrophication

1. M = mesotrophic; O = oligotrophic; O-M = oligo-mesotrophic
2. (1) Pinsent et al. 1974; (2) Ashley et al. 1998, MS; (3) Ashley et al. 1999a, MS; (4) Andrusak et al. 2001a MS; (5) Wright 2001; (6) Hyatt & Rankin 1999; (7) Pieters et al. 1998 MS; (8) Pieters et al. 1999, MS; (9) Lasenby et al. 1986; (10) Ashley et al. 1999b, MS; (11) Andrusak et al. 2001b, MS; (12) Ashley & Thompson 1993, MS; (13) Northcote 1973; (14) Clarke & Bennett 2002; (15) Bowles et al. 1991; (16) Beattie & Clancey 1991; (17) Richards et al. 1991; (18) Northcote 1991.

4.3 Results of Model Analyses (Preliminary analyses)

We completed a number of analyses for this report. We found it necessary to first conduct a set of preliminary analyses in order to determine base case model settings, demonstrate that the model could reproduce the behaviour of the Osoyoos stock for reasonable parameter assumptions, illustrate the effects of natural variability on model results, explore competition effects, and answer some specific questions raised at the October 2002 workshop. We then applied what we learned from our preliminary analyses to develop a framework for modelling and comparing the three alternative introduction methods. We present these analyses in the *Experimental Analyses* section.

We used the upgraded version of the life-cycle model (V2. 2; see Appendix C for a version history of the model), began each simulation in water year 1973, and simulated over 25 years.³ Run definitions and output for the model runs presented here are archived in the database “OkSockeye(Report).mdb,” which is being distributed with version 2.2 of the OkSockeye life-cycle model (available from the Okanagan Nation Fisheries Commission).

4.3.1 Overview of Preliminary Analyses

Analysis 1:

Our objective in this analysis was to produce equilibrium Osoyoos sockeye Wells dam escapements similar to the geometric mean of historical Wells dam escapements from 1973 to 1996 (about 20,000). We did this first by removing all sources of natural variability as well as competition with mysis.

We chose to adjust only the smolt-to-adult survival rate to achieve this objective because our earlier analysis (from June 2002 and at the October 2002 workshop) demonstrated that the persistence of the Osoyoos stock was very sensitive to this parameter. Additionally, the default egg-to-fry survival rate (about 20%) is at the upper bound of those reported for sockeye by Bradford (1995) (about 20%) and the fry-to-smolt survival rate realised during modelling (about 30%) also tends to be quite high. So, while setting these rates higher would improve overall survival, such increases would be less likely to occur naturally.

By “removing all sources of natural variability”, we mean no random variation in the natural component of the egg-to-fry survival rate, a constant age structure, a constant smolt-to-adult recovery rate (SAR), a constant per project survival, and constant stock composition, flow, and total phosphorous. For all factors except SAR, we set these constant values to the long-term average (e.g. the constant age structure was the average proportion at each age over the seven years of data available).

³ Results reported in the Jan 8 2003 Draft of this report used version 2.1.2 of the model. Results in this report used v.2.2 of the model (the difference between the two versions is described in Appendix C). Sensitivity analyses showed that the two versions produce results that are identical, except when very large numbers of fry are introduced into Skaha Lake. Results for these preliminary analyses were unchanged.

Analysis 2:

Our objective in this analysis was to explore the effects of various sources of natural variability on overall equilibrium model results. Factors in the model that include a component of natural variability are:

- sockeye egg to fry survival rate;
- sockeye age structure (proportion at each age class);
- mean, maximum, and minimum flows in the Okanagan River during sockeye spawning and incubation;
- smolt-adult survival rate (SAR);
- sockeye upstream survival rate;
- proportion of Okanagan/Wenatchee sockeye (this is used in the model to determine total Okanagan + Wenatchee returns to the Columbia River mouth, which determines commercial harvest rates in the Lower Columbia River); and
- total phosphorus concentrations.

Analysis 2a:

Starting with the equilibrium parameter values for the Osoyoos stock from Analysis 1, we added all natural variability back in to illustrate the impact on the equilibrium result.

Analysis 2b:

Starting with the equilibrium values determined in Analysis 1, we added all natural variability back in as well as competition with mysis. Note that this run is essentially a “base case”, because it includes all sources of variability, and includes mysis competition.

Analysis 2c:

Starting with the equilibrium values determined in Analysis 1, we then added the components of natural variability back in one by one:

- 2c0** – Analysis 1 + Added competition with mysis
- 2c1** – Analysis 2c0 + Added variability in sockeye egg to fry survival rate
- 2c2** – Analysis 2c1 + Added variability in age structure
- 2c3** – Analysis 2c2 + Added variability in annual mean, maximum flows during sockeye spawning and incubation
- 2c4** – Analysis 2c3 + Added year to year variability in SAR
- 2c5** – Analysis 2c4 + Added variability in upstream survival rate
- 2c6** – Analysis 2c5 + Added variability in Okanagan/Wenatchee proportions
- 2c7** – Analysis 2c6 + Added variability in Total Phosphorus concentrations

Analysis 3:

Determine equilibrium settings for Skaha Lake kokanee and mysis.

Analysis 4a:

Starting with the equilibrium settings determined in Analysis 3, we explored the strength of the competitive interactions between kokanee and mysis by varying the feeding rate for each species 0.5, 1 (base), and 1.5 times its base-case value.

Analysis 4b:

Starting with the equilibrium settings determined in Analysis 3, we explored strength of competitive interactions at between kokanee and mysis and sockeye fry at different levels of sockeye fry supplementation to Skaha Lake. We varied the competitive ability the same way as in Analysis 4a.

Answers to questions raised at the October 15th-17th workshop: While the analyses above were crucial to our understanding of model behaviour, there were several specific questions raised at the October workshop. We used the results from the preliminary analyses and some additional model runs to address the following questions:

- How does variable SAR affect Osoyoos results? We compared results for constant and variable SAR time series.
- What conditions are required to support 80,000 kokanee spawners in Skaha Lake?
- What conditions are required for sockeye to establish in Skaha Lake?
- How do sockeye, kokanee, and mysis impact one another?
- How many fry can be introduced before there is an impact on kokanee?

4.3.2 Results for Analysis 1: Equilibrium settings for sockeye in Osoyoos Lake

Without natural variability or mysis, an SAR of 2.65% gives an equilibrium of 20,000 adults at Wells (Figure 4-3). This is considerably higher than the default value derived from Fryer (1995) of 0.4% (see Peters and Marmorek. 2003), but still less than the mean of 6.2% reported in Bradford (1995) for 12 sockeye stocks. An SAR of 2.65%, therefore, does not seem unreasonable given the negative impact of passage through the Columbia hydrosystem and the effects of poor ocean conditions during recent decades for many Columbia River chinook stocks (e.g. Deriso et al. 2001).

4.3.3 Results for Analyses 2a-c: Effects of variability

When natural variability was added back in (Analysis 2a), Wells escapement varied about the equilibrium value until the last few years of the simulation when it dropped well below the equilibrium value (Figure 4-3). When both natural variability and mysis were added back in, the pattern of variation was similar to natural variability only, but the escapement values were lower (Figure 4-3).

Figure 4-4 summarises the impact of different components of natural variability on adult escapement to Wells dam (Analysis 2c). It is interesting to note the overall trend with no variability and with mysis (run 2c0), compared to no variability and no mysis (equilibrium, Figure 4-3). Increasing the density of mysis from 6/m² to about 130/m² (the simulated mysis density in Osoyoos Lake after 25 years) reduces the equilibrium number of sockeye spawners from 20,000 to 6,000 fish.

Figure 4-4 also shows the results of scenarios with sources of natural variability added in one by one. Variability in some factors, such as egg-fry survival have an overall positive (upward) effect on escapement while others, such as spawning and incubation flows, have an overall negative effect. Finally, Figure 4-4 also shows the observed number of adult sockeye at Wells Dam from 1973 to 1998. The year-to-year trends don't track exactly between the modelled and actual data, probably because the random number sequence used to generate egg-to-fry survival does not reflect natural variations in egg-to-fry survival, but the simulated overall range of adult returns is similar to the actual range over the 1973-1997 time period, and the overall downward trend in simulated escapement is consistent with the overall trend seen in the observed values. This suggests to us that the model is doing a reasonable job of capturing the major factors that affect long-term production of Okanagan sockeye.

Descriptions of each of the Analysis 2c scenarios, further summary graphs for fry and smolts, and additional graphs showing various combinations of natural variability components can be found in Appendix B.

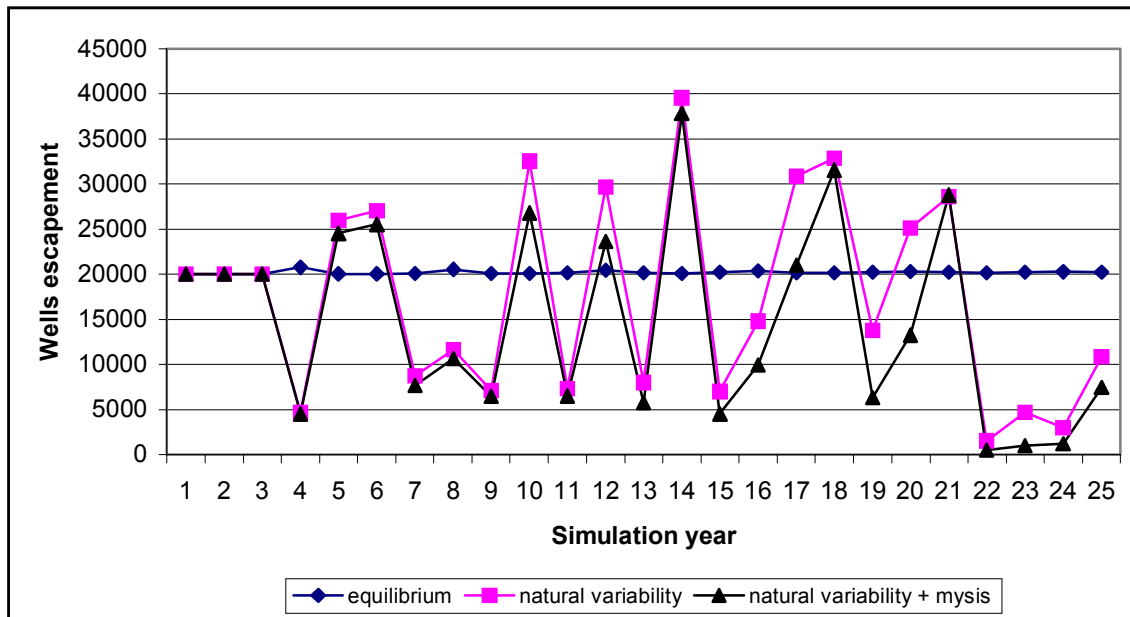


Figure 4-3: Comparison of Wells escapement for the Osoyoos stock under conditions of equilibrium (Analysis 1), natural variability (Analysis 2a), and natural variability + mysis (Analysis 2b).

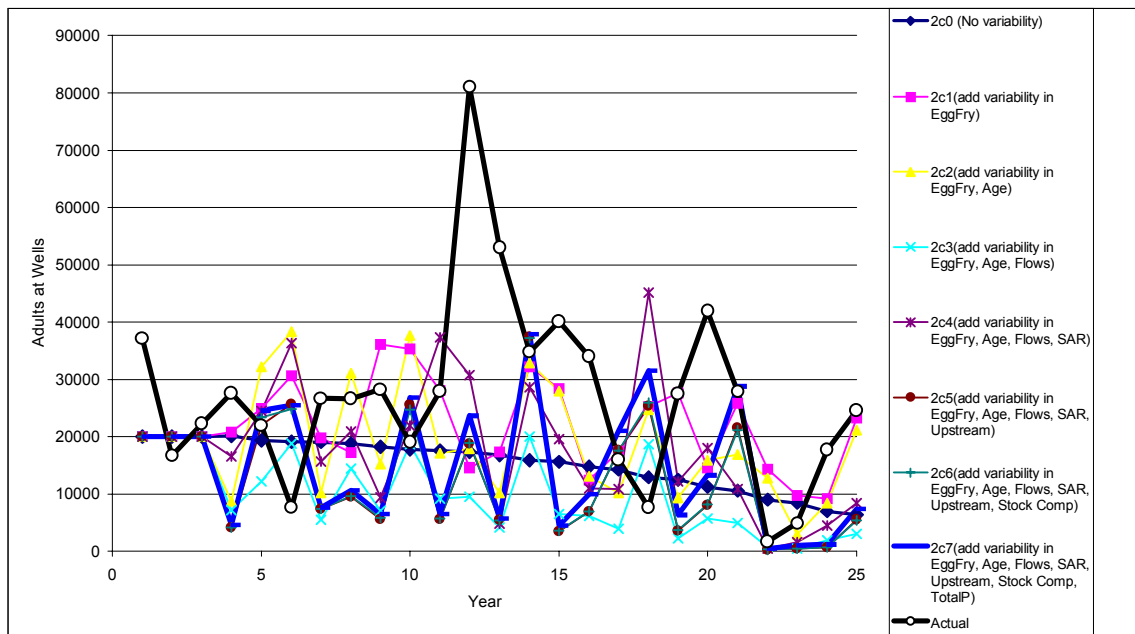


Figure 4.4. Comparison of adult escapement to Wells dam for the Osoyoos stock for various components of natural variability, all with mysis (Analysis 2c), to actual historical escapement from 1973 (Year 1) to 1997.

4.3.4 Results for Analysis 3: Equilibrium values for kokanee and mysis in Skaha Lake

Kokanee equilibrium (age-specific abundance, length-at-age) without mysis and no variability

Without mysis competition and with no variability in egg-to-fry survival or other components of natural variation, kokanee equilibrated at the following age-specific abundance and length-at-age:

Table 4-1b: Equilibrium abundance and body lengths for kokanee (without mysis).

Age	Abundance	Length (mm)
0	121799	n/a, constant at 55
1	48665	189
2	29153	250
3	20361	277
4	2785	289

Mysis equilibrium (immature and mature density) with no kokanee

Without kokanee and with no variability in total phosphorous, mysis immature and mature densities equilibrated at approximately 110 and 40 respectively.

Kokanee and mysis equilibrium with both together (no variability in kokanee egg-to-fry survival rate, plus no variability in other factors as for the Osoyoos sockeye in Analysis 2). We conducted this analysis to provide a stable starting point for the experimental analyses. Starting from equilibrium values would remove as much as possible the influence of trend on comparison of results “Before” and “After” treatment. There was little change in the mysis equilibrium densities (immature densities = 114/m², mature densities = 41.5/m²), but the age-specific equilibrium values for kokanee changed considerably (table below). When we added natural variability back in and started a simulation with the new equilibrium values, both kokanee abundance and mysis density ranged above their equilibrium values (Figure 4-5).

Table 4-1c: Equilibrium abundance and body lengths for kokanee (with mysis).

Age	Abundance	Length (mm)
0	8054	n/a, constant at 55
1	3263	193
2	1965	256
3	1357	282
4	142	295

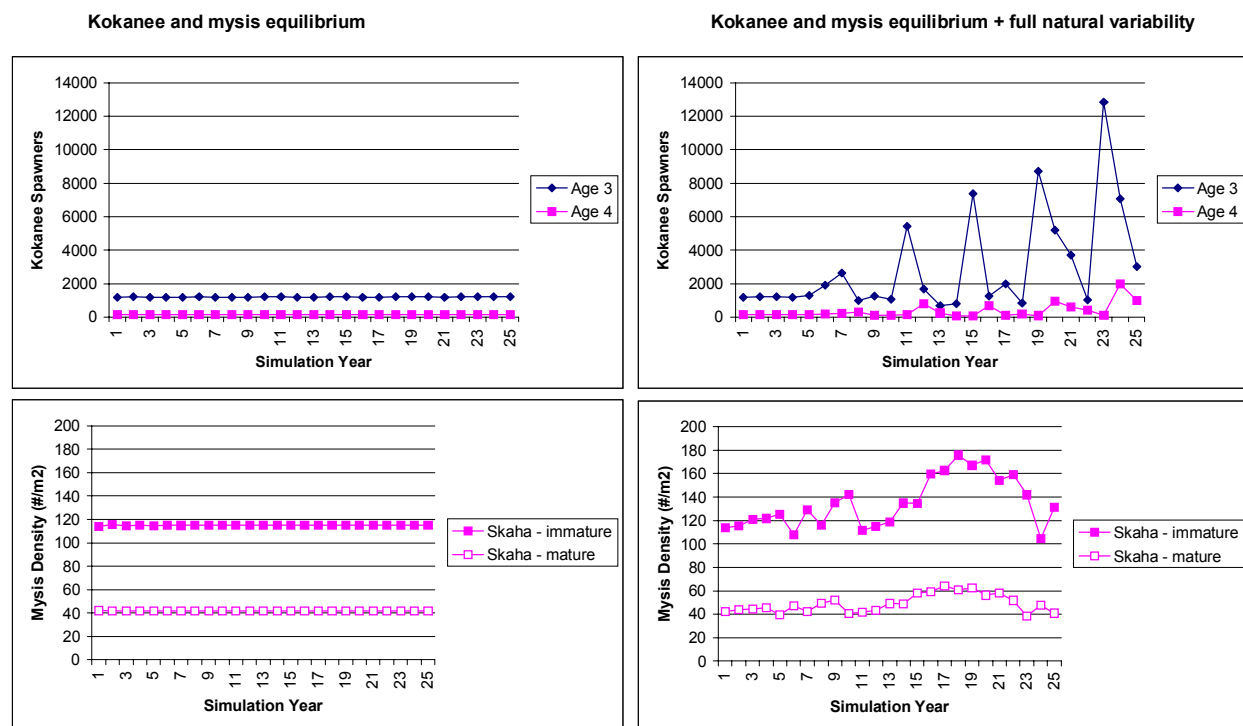


Figure 4-5: Comparison of simulated kokanee Age 3 and 4 abundance and mysis densities in Skaha lake under equilibrium conditions with no natural variability (left panels) and starting at equilibrium conditions, but with full natural variability added back in (right hand panels).

4.3.5 Results for Analysis 4: Explore strength of competitive interactions at different levels of fry supplementation to Skaha Lake

The purpose of this analysis is to explore the strength of the competitive interactions between sockeye, kokanee and mysis in the life-cycle model.

We started with the equilibrium, no variability, scenarios developed in Analyses 1-3 and then varied the feeding rates from their base values (for sockeye, kokanee, and mysis) and the level of sockeye fry supplementation (200 and 800 fry/ha). We maintained a constant rate of fry supplementation (e.g., 200 fry/ha) in each year of a simulation, as long as the number of female Osoyoos sockeye was above the threshold where take for hatchery broodstock was allowed (we assumed a threshold of 5,000 spawners). To maintain a constant level of supplementation we blocked the return of model Skaha adults to Skaha Lake by setting the thermal barrier between Osoyoos and Skaha Lake to 0. Each simulation began in water year 1973 and was 25 years long.

Note that for our base case simulations, realised kokanee fry/ha ranged from about 60-75 fry/ha over the 5-year index period. Therefore, a sockeye fry supplementation rate of 200 sockeye fry/ha roughly quadrupled the total fry density in Skaha Lake (kokanee + sockeye fry).

We used the following performance measures, calculated over simulation years 5-9:

- sockeye – average fry-to-smolt survival;
- kokanee – average fry-to-Age 0 survival, average number of spawners;
- mysis – average immature-to-mature survival, average density of immature and mature mysis.

We started at year five to minimise initialisation effects and averaged over five years to reduce the influence of trends (e.g., a trend in fry-smolt survival may arise due to changes in fry production resulting from changes in spawner abundance, which can arise from factors other than in-lake competition).

Kokanee and mysis:

We first explored the competitive interactions between kokanee and mysis in Skaha Lake without sockeye fry supplementation to provide a baseline for comparison (Figure 4-6). Note that for base case parameter settings, the equilibrium density values ($\#/m^2$) for immature and mature mysis were about 114 and 41.5 respectively. This is slightly below recent estimates of immature mysis densities in Skaha Lake of 150-250/ m^2 (K. Hyatt, DFO, pers. comm.)

The main result is that kokanee performance measures are much more sensitive to uncertainty in the kokanee and mysis feeding rate than mysis as demonstrated by the relative spacing and steepness of the lines in the top panels of Figure 4-6. For example, if the kokanee feeding rate is held at its base-case value (i.e. 1X), increasing the mysis feeding rate by 1.5X decreases the kokanee fry-to-Age 0 survival rate from 0.4 to 0.32 (Figure 4-6, top left panel). However, holding the mysis feeding rate constant at its base value (1X) and increasing the kokanee feeding rate by 1.5X results in only a 1% decrease in the mysis immature-to-mature survival rate (Figure 4-6, top right panel).

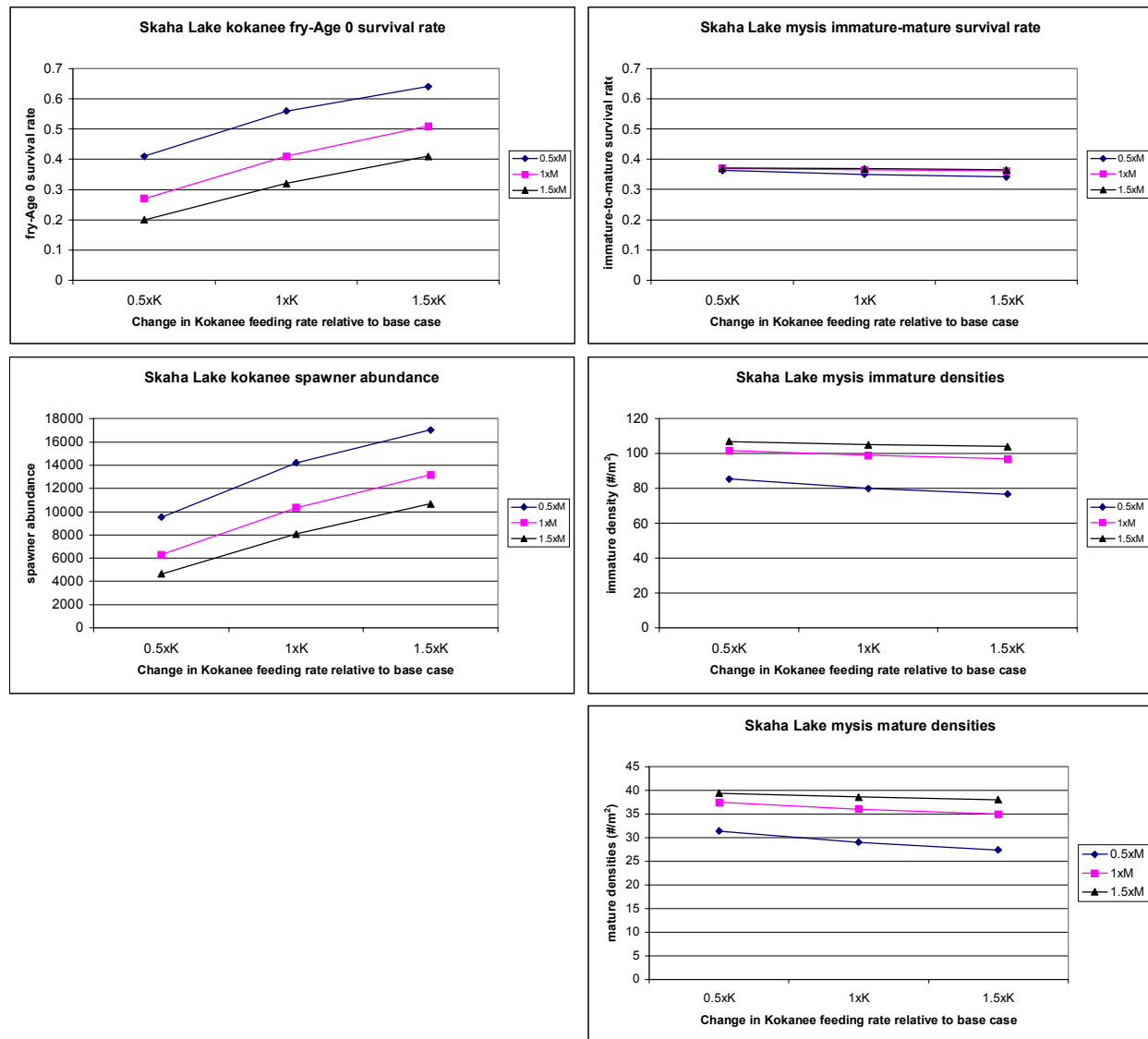


Figure 4-6: Relative sensitivity of kokanee and mysis survival and population level performance measures to variation in feeding rate. The top left panel shows the response of kokanee fry-to-Age 0 survival rate to changes in the kokanee feeding rate. The top right panel shows the response of the mysis immature-to-mature survival rate to changes in the kokanee and mysis feeding rate. Each line represents a different mysis feeding rate, while each point on a line represents a different kokanee feeding rate (shown on the x-axis).

Sockeye, kokanee, and mysis

Next we included fry supplementation at levels that ranged from 200 to 7500 fry/ha, while varying the mysis feeding rate as before and varying the sockeye feeding rate relative to a constant kokanee feeding rate (at the base case value of 8.5 kg/kg). We assumed that the kokanee feeding rate was more certain than the sockeye feeding rate which was merely set equal to the base case kokanee rate as a default. In comparison, the geometric mean fry/ha for Osoyoos Lake (1972-2001) is 5,426 fry/ha, (max: 19,610; min: 403) based on the observed escapement to Wells dam (1972-2001) and assuming an 87% pre-

spawning survival rate, a female ratio of 52%, a weighted fecundity of 2674 eggs/female, an egg-to-fry survival rate of 20%, and an area of 1000 ha for the north basin of Osoyoos Lake.

We found that the survival performance measures were insensitive to stocking densities up to 1000 fry/ha, but showed greater sensitivity for levels above 1000 fry/ha with the kokanee and mysis survival rates gradually declining and the sockeye rates more rapidly increasing (Figure 4-7). The sockeye fry-to-smolt survival rate increased up to 5000 fry/ha and then began to decline.

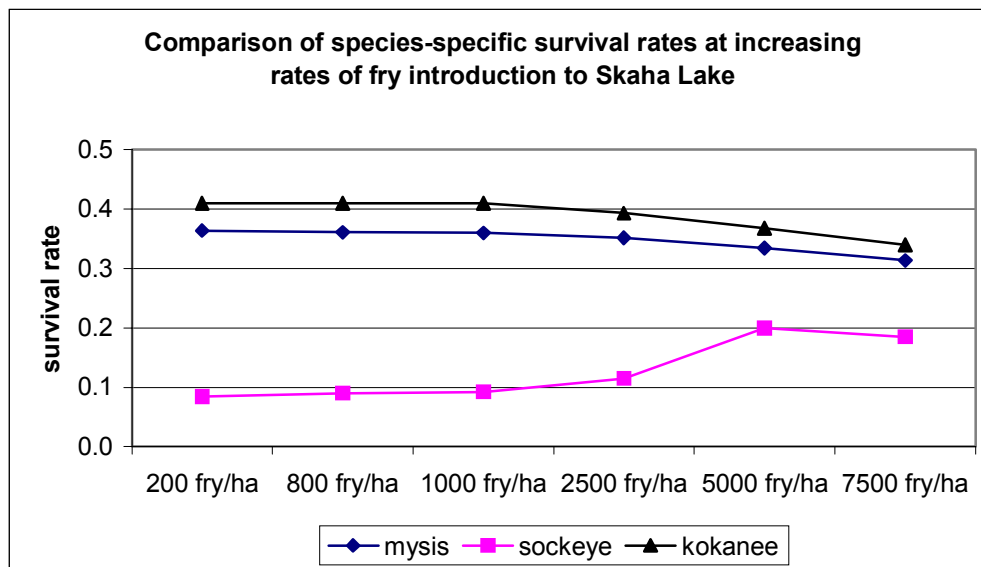


Figure 4-7: Sensitivity of survival rate performance measures to increasing rates of sockeye fry introduction.

We explored interactions for various species combinations and levels of fry introduction (Figure 4-8). Kokanee are sensitive to mysis, but not sockeye. Sockeye are sensitive to both kokanee and mysis, but more sensitive to mysis. Mysis are insensitive to either sockeye or kokanee. These results are insensitive to sockeye fry stocking rates of up to 800 fry/ha.

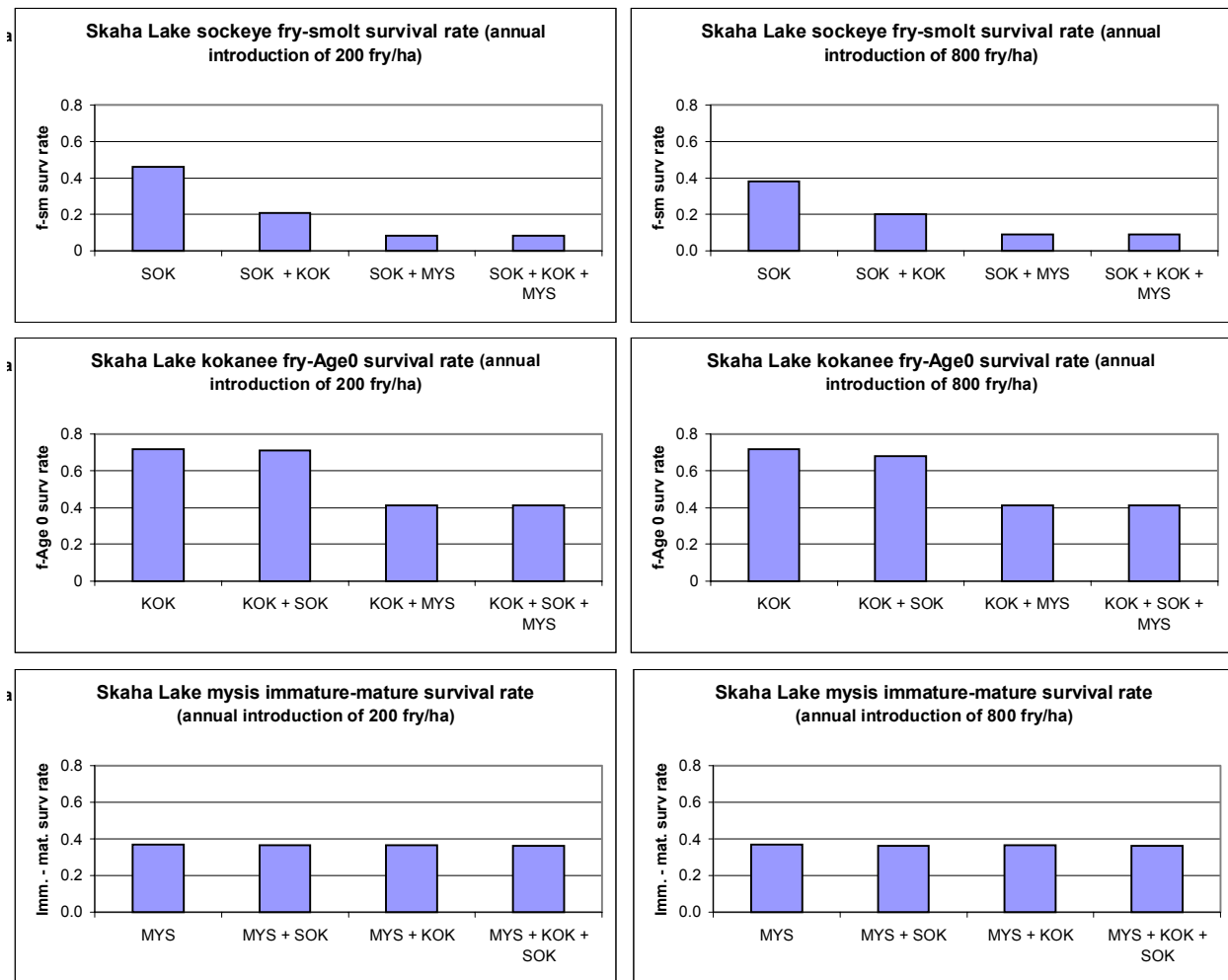


Figure 4-8: Relative sensitivity of survival performance measures to species interactions for base case feeding rates and two levels of sockeye fry stocking rate (200 and 800 fry/ha). The x-axis labels indicate the species combination for each scenario (e.g., MYS + SOK means mysis and kokanee only).

We then explored the competitive interactions between the species in more detail over different levels of feeding rates (Figure 4-9). These results show that sockeye are somewhat sensitive to uncertainty in mysis and sockeye feeding rates (top left panel), but the magnitude of this response is insensitive to the fry stocking rate up to 800 fry/ha (compare the top left and right panels). Kokanee are insensitive to uncertainty in the sockeye fry feeding rate (middle left panel) and the fry stocking rate (compare the middle left and right panels); however, as shown previously, they are sensitive to uncertainty in the mysis feeding rate. Mysis are insensitive to uncertainty in the sockeye feeding rate (bottom left panel), though they do show a very slight decline in survival at the highest sockeye feeding rate under the highest fry stocking rate (bottom right panel).

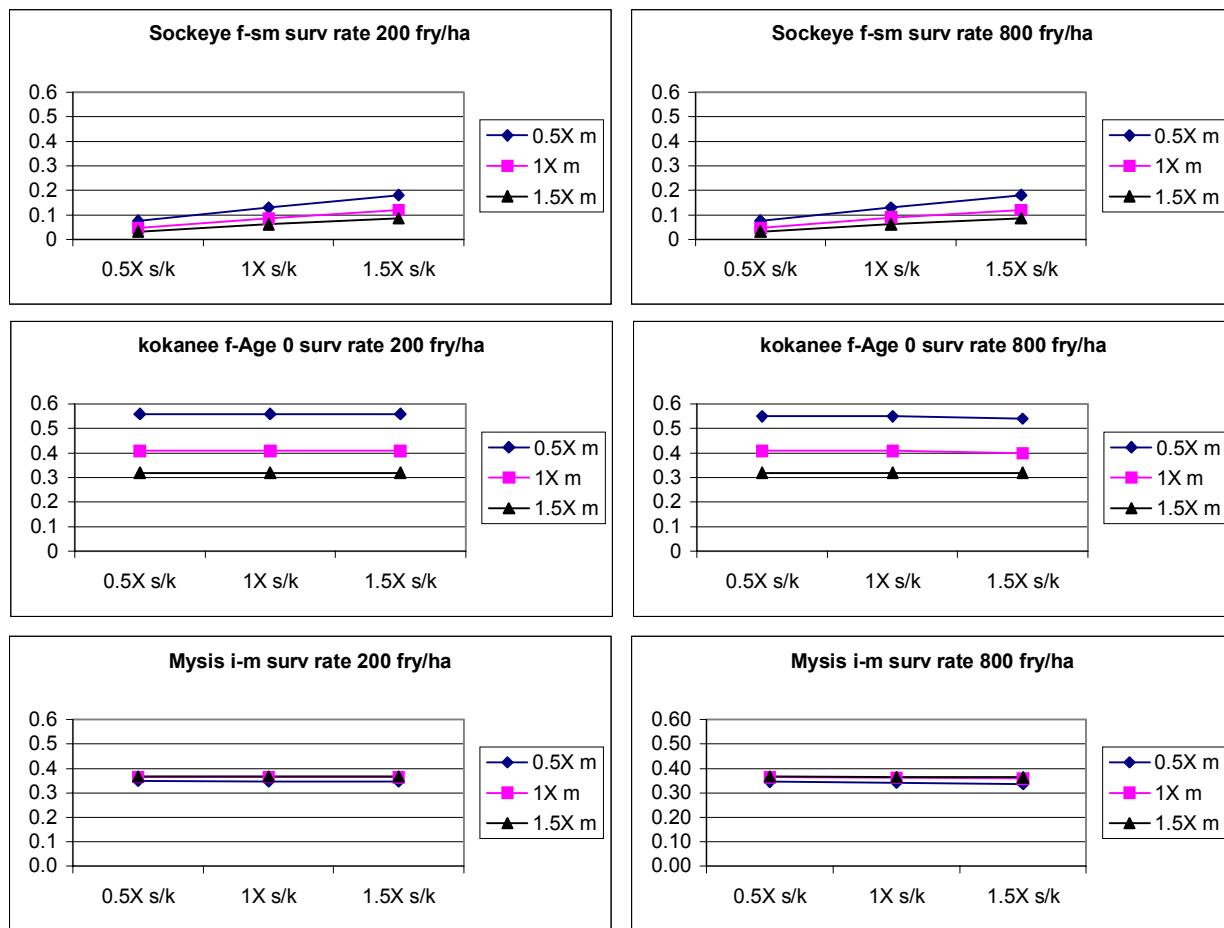


Figure 4-9: Relative sensitivity of survival performance measures by species to uncertainty in feeding rates and two levels of fry stocking rate (200 and 800 fry/ha). The ratio of the sockeye to the kokanee feeding rate is on the x-axis, the mysis feeding rate is the legend. Survival rate is on the y-axis.

These results arise from both biomass and conversion efficiency effects. In a given simulation year, the partitioning of available total lake capacity by species is a function of each species' production. For each species, production is a function of its abundance (or density in the case of mysis), average weight (biomass), and the production-to-biomass (P:B) ratio, which is in turn a function of the species-specific feeding rate and conversion efficiency (e.g., see Design Document equations, 4-12, 4-13 and 5-3). Sockeye require a portion of the available total lake capacity for smolt production (affects fry-to-smolt survival rate), while kokanee require a portion of lake capacity for Age 0 production (affects fry-to-Age0 survival rate) as well as production in older, heavier, age-classes. Mysis require a portion of total lake capacity for production in both the immature and mature stages (affects immature-to-mature survival rate). The sockeye and kokanee have default feeding rates of 8.5 Kg/Kg for the fry stages while kokanee have default feeding rates of 3.7 Kg/Kg for ages 0 to 4. Both sockeye and kokanee use the same equation for conversion efficiency. The mysis have a feeding rate of 18 and 25 Kg/Kg for the mature and immature life stages respectively (default parameter values for feeding rates are from Kay 2002)

Conversion efficiency effects dominate results under a given fry stocking rate (e.g., Figure 4-8, left column). For these analyses, the observed effects are a function of conversion efficiency because initial

abundances/densities, age-specific weights, and conversion efficiency equation parameters are held constant. Adjusting the feeding rate can be interpreted as a proxy for adjusting conversion efficiency because the P:B ratio is the product of feeding rate and conversion efficiency.

Biomass effects dominate when comparing results between fry stocking rates (e.g., Figure 4-7). The relatively high initial biomass of mysis (function of initial density and weight) and their high feeding rates means they appropriate the largest share of the available lake productive capacity (Figure 4-10, top panel), which explains their strong effect on sockeye and kokanee (e.g., Figures 4-8, 4-9). For the initial condition used in these analyses, the starting biomass of sockeye fry, kokanee (all age classes), and mysis (both stages) under the 800 fry/ha introduction rate is 0.2, 8.3 and 10.8 kg/ha respectively; sockeye biomass is only about 1.9% that of mysis. Kokanee are able to obtain a medium level of capacity due to their relatively higher biomass, which is also why they have a stronger impact on sockeye than sockeye do on them. The largest share goes to the older kokanee age classes. As the biomass of sockeye increases, they obtain a larger share of the available lake capacity and have a stronger impact on mysis and kokanee (Figure 4-10, bottom panel). At a stocking rate of 7500 fry/ha, the biomass of sockeye fry increases to 1.5 kg/ha, about 14% of the initial mysis biomass.

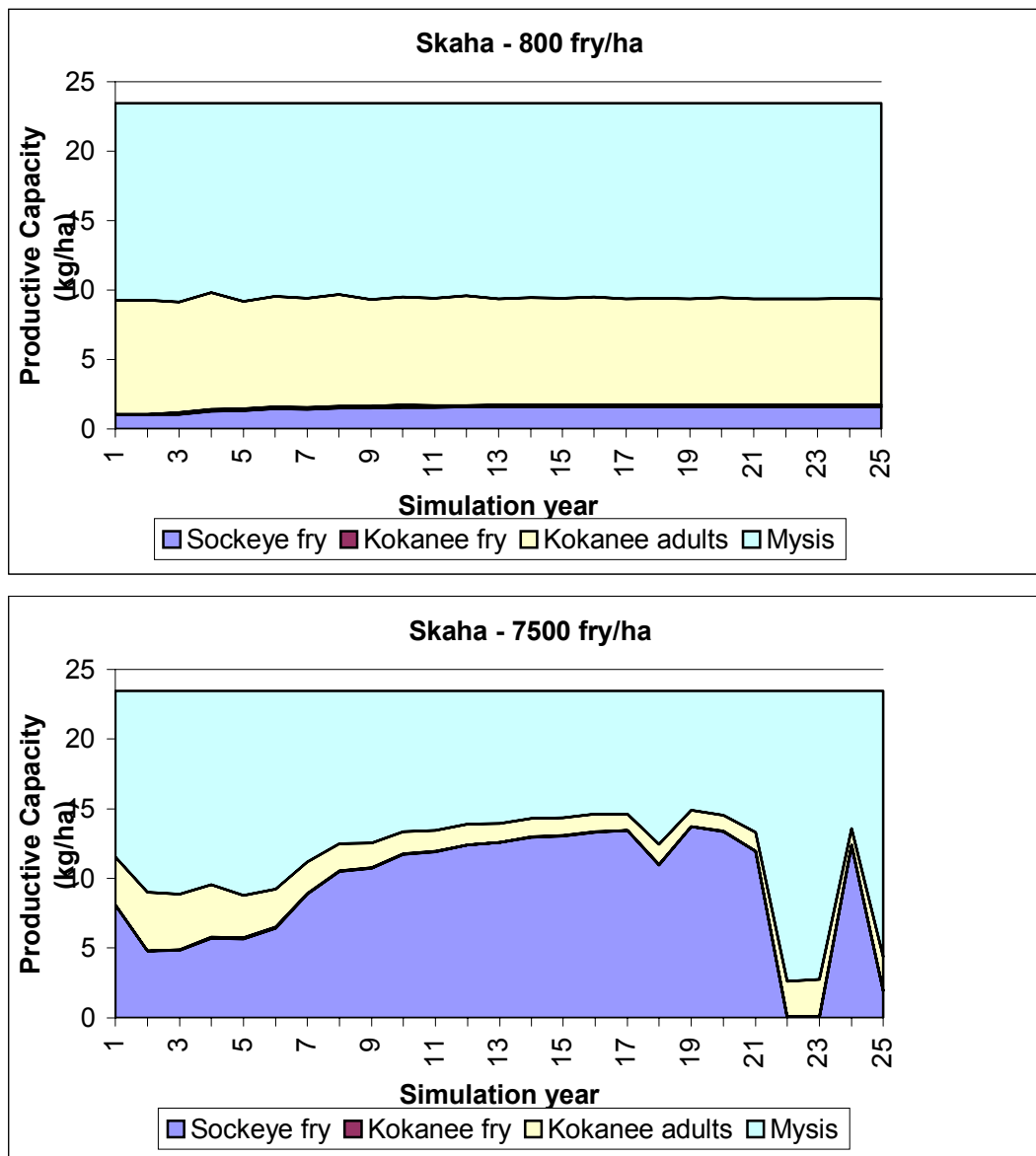


Figure 4-10: Partitioning of Lake productive capacity between sockeye, kokanee and mysis at fry introduction rates of 800 and 7500 fry/ha. These results are from the same runs used to produce the survival estimates shown in Figure 4-7.

4.3.6 Answers to specific questions

We used the results from the above analyses plus some additional model runs to address specific questions raised at the October 15-17 2002 and January 14-15 2003 workshops.

Compare results for constant and variable SAR time series:

For preliminary runs of the life-cycle model (V1.0, June 19, 2002) it was necessary to increase the mean smolt-to-adult recovery rate (SAR) to 2.5% for the Osoyoos and Skaha sockeye stocks to persist for at

least 20 years. This is about 6.25 times higher than the derived base case value of 0.4% (Peters and Marmorek 2003). In this model version, the mean SAR is constant; a question raised at the October 15-17 workshop was how year-to-year variation in SAR might affect simulation results. It might be that despite a low mean SAR periodically high SAR values would allow the Osoyoos sockeye population to persist.

We explored this possibility by modifying the life-cycle model code to use year-to-year variability in the modelled SAR time series. We then derived a time series of SAR deviations from the geometric mean of Barkley Sound coho SAR data (1973 to 1997) (data provided by Kim Hyatt, DFO) under the assumption that Osoyoos sockeye SAR deviations would show a similar pattern. The Barkley sound time-series is not as long as the data series used by the model (1944-1999), so we increased its length by assuming the derived SAR deviations repeated over time, an assumption that is probably overly pessimistic for SAR conditions prior to 1973 (Figure 4-11). The deviations are used as multipliers to the assumed mean SAR entered in the model interface. Independent estimates of a mean SAR for Osoyoos were not available to us at the time of this analysis.

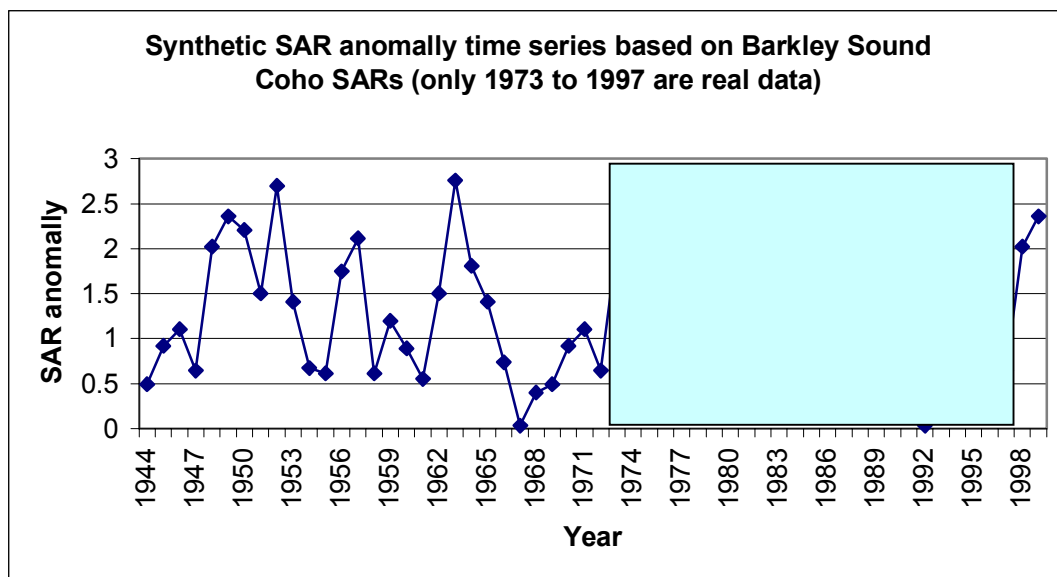


Figure 4-11: Synthetic time series of deviations in Smolt-to-Adult return rate (SAR) (1944-1999) used for modelling. The shaded area indicates the time series of deviations (1973-1997) derived from the Barkley Sound coho SAR data provided by Kim Hyatt, DFO.

We compared the results of a simulation with all components of natural variability (Analysis 2a) to those for a run with all components of variability except variable SARs (Figure 4-12). Including variability in SARs improved the performance of the modelled Osoyoos stock, in terms of Wells dam escapement. Escapements were generally higher over the length of the simulation. So, in general, it is possible for periodically high SAR values to increase the persistence of the Osoyoos stock. However, these results are for only one version of the SAR time series, based on a coastal coho stock from the West Coast of Vancouver Island. It would be useful to explore a wider range of SAR time-series based more closely on the Columbia River/Ocean conditions that interior Osoyoos sockeye might experience.

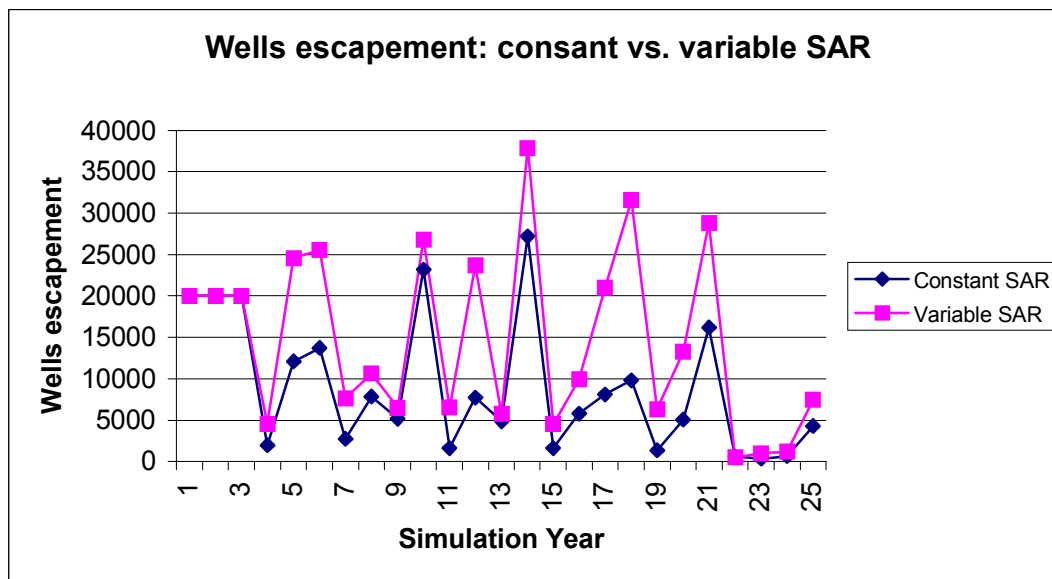


Figure 4-12: Comparison of model results for Wells dam escapement of Osoyoos sockeye under conditions of variable and constant mean SAR.

What conditions are required to support 80,000 kokanee spawners in Skaha Lake?

At the October 2002 workshop it was noted that in the late 1960s, hatchery egg recovery records indicate that Skaha Lake supported an adult population of approximately 100,000 kokanee. However, model kokanee abundance produced using the default (base case) parameter settings for version 1.0 of the life-cycle model had a geometric mean of about 9774 adults (ages 3 + 4) over a 20 year simulation. This raised the question, “Under what conditions would the model produce a Skaha Lake adult kokanee population of 80,000-100,000?”

We addressed this question through a series of simulations starting from base case parameter setting for kokanee. We considered the following scenarios as examples of the factors that have likely most affected the kokanee population since late 1960s.

- Increased competition with mysis (affects fry-Age 0 survival rate): In the late 1960s there may not have been mysis in Skaha Lake. During base model runs, mysis are initiated at set densities and then increase over time. We compared base case results with mysis competition to a scenario without mysis.
- Decrease in competitive ability (feeding rate, kg consumed per kg of biomass). This represents a hypothesis that there have been changes in kokanee competitive ability apart from competing with increased abundance of mysis over time, perhaps through impaired feeding ability under conditions of increased milfoil weed.
- Decrease in area of kokanee spawning habitat (m²) (decrease in habitat quantity). In the late 1960s there may have been a greater quantity of spawning habitat for kokanee.
- Decrease in kokanee egg-to-fry survival rate (decreased habitat quality). In the late 1960s there may have been better quality spawning habitat for kokanee.

The impact of changing total phosphorous levels over time (affects fry-Age 0 survival rate) may also be worth exploring. Lake productivity has declined since the 1960s as a result of implementation tertiary sewage treatment in Okanagan cities.

Our performance measures were the average kokanee egg-to-fry survival, average kokanee fry-to-Age 0 survival and average kokanee Age3 and 4 abundance over the last five years of a twenty-year simulation starting water year 1985, there was no sockeye supplementation. We used version 1.0 of the life-cycle model, but explore the effects of using the most recent version (v. 2.1.2).

Our results show that the model parameters can be adjusted in combination to produce adult kokanee abundance (Age 3 + 4 spawners) in the range of 80,000 adults (Table 4-2). For example, removing competition (no mysis, no sockeye), doubling egg-to-fry survival rates (improved habitat quality) and tripling habitat area (m²) (increased habitat quantity) achieved an average of 78,258 adults. Just removing mysis, or increasing habitat area alone could not achieve this result. Scenarios with average spawners less than 80,000 achieved more than 80,000 in some years (Figure 4-13).

Note that because we used version 1.0 of the life-cycle model for the bulk of this analysis, results will be different using version 2.1.2, but our general conclusions will be unchanged. For example, the numbers in yellow highlight in the right hand column of Table 4-2 were derived using V2.1.2 with the equilibrium form of the kokanee model (Analysis 3) and no variability. They show the same pattern of increasing average abundance as first mysis are removed, then habitat is increased, then egg-to-fry survival is doubled, although the actual values are lower than for the V1.0 results. This is due to the exclusion of variability. When variability is added back in, the values increase, shown by the number in red highlight, which was derived using the V2.1.2 scenario with variability added back in. It is much larger than the V1.0 result because the model is initiated using equilibrium values for kokanee abundance and length-at-age.

Table 4-2: Conditions necessary to achieve 80,000 kokanee in Skaha Lake. Results were calculated using V1.0 of the life-cycle model (June 19, 2002). For comparison, the yellow highlighted results were calculated using V2.1.2 and the equilibrium kokanee model with no variability (Analysis 3). The red highlighted number was obtained using V2.1.2 and equilibrium kokanee model with full variability added back in.

Scenario	Egg-to-fry survival rate	Fry-to-Age 0 survival rate	Avg. Age 3-4 abundance over years 16-20
Base case	0.057	0.46	7950
No mysis	0.057	0.72	20706 (19,929)
Double habitat, no mysis	0.057	0.67	29872 (27,773)
Triple habitat, no mysis	0.057	0.64	36003
Double feeding rate, no mysis, base habitat	0.057	0.81	25281
Double egg-to-fry survival, no mysis, base habitat, base feeding rate	0.115	0.59	44800 (41,951)
Double egg-to-fry survival, double habitat	0.115	0.53	64601 (58,892)
Double egg-to-fry survival, triple habitat	0.115	0.50	78258
Double egg-to-fry survival rate, double habitat, double feeding rate	0.115	0.62	85231 (79,897) (118,159)

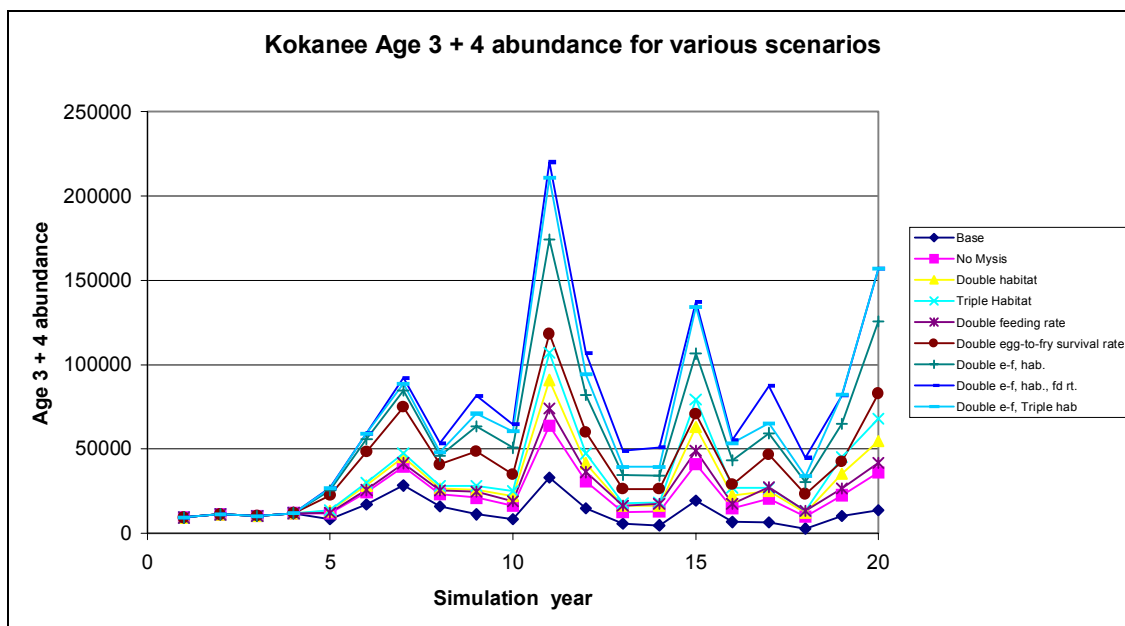


Figure 4-13: Results for 80,000 Kokanee analysis. Scenarios described in Table 4-2. Results were calculated using V1.0 of the life-cycle model (June 19, 2002).

What conditions are required for sockeye to establish in Skaha Lake?

At the January 14-15 workshop, the group explored conditions necessary to establish a new sockeye stock in Skaha Lake. The most promising results were found for removing barriers in combination with trapping and placing adults into Skaha Lake along with mysis harvest in both Osoyoos and Skaha Lake (at a constant 50% harvest rate) (Figure 4-14).

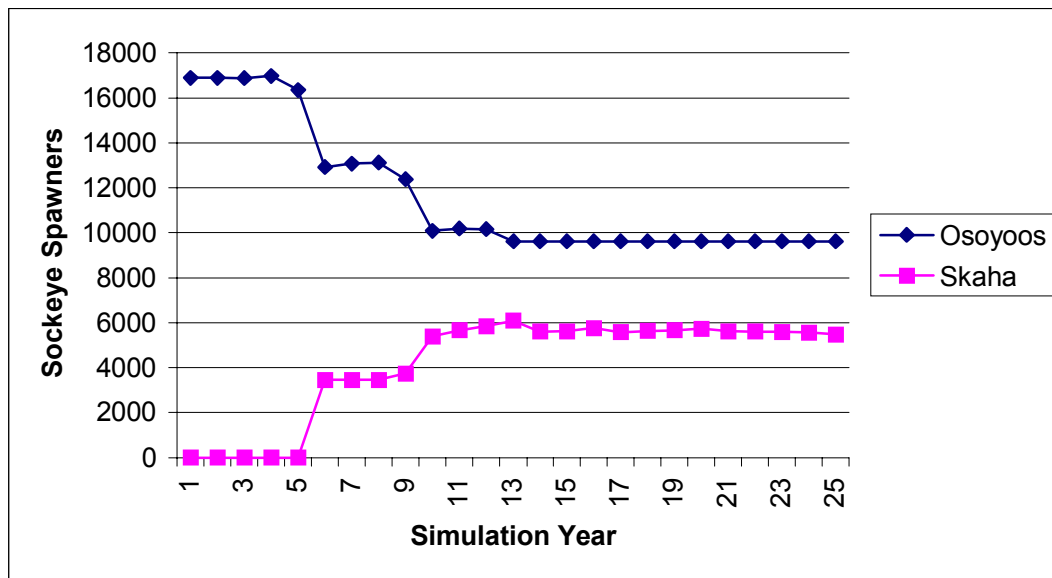


Figure 4-14: Results for a run that provided stable returns to Skaha Lake – 50% mysis harvest in both lakes, trap and truck.

How do sockeye, kokanee, and mysis impact one another?

For the base case parameter settings, sockeye fry have relatively little impact on kokanee, or mysis (Figures 4-8 and 4-9). This results holds even when their competitive ability (feeding rate) and abundance are set much higher than base case levels. Kokanee have some impact on sockeye, but little impact on mysis (Figures 4-7 and 4-8). Mysis have a large impact on both sockeye and kokanee (Figures 4-7, 4-8 and 4-9).

How many fry can be introduced before there is an impact on kokanee?

For the base case parameter settings, kokanee are insensitive to sockeye fry up to levels of 1000 sockeye fry/ha (Figure 4-7). For levels above this, there is a gradual decline in the kokanee fry-to-Age 0 survival rate from about 41% to about 35%.

4.4 Results of Model Analyses (Experimental analyses)

We built a framework for simulating examples of the three alternative methods of sockeye introduction discussed at the October 2002 workshop. For each analysis we calculated the results without variability to see the “true” impact on a performance measure and then added variability back in to simulate an

estimating the “true” change in the presence of “natural” variability. There are many possible experimental variations; for brevity, we chose to provide a single example in each of the three categories:

- Analysis 5a:* Hatchery fry supplementation experiment without natural variability.
Analysis 5b: Hatchery fry supplementation with natural variability.
Analysis 5c: Hatchery fry supplementation without natural variability with mysis harvest.
- Analysis 6a:* “Trap and transport” experiment without natural variability.
Analysis 6b: “Trap and transport” experiment with natural variability.
- Analysis 7a:* “Remove barriers” experiment without natural variability.
Analysis 7b: “Remove barriers” experiment with natural variability.

4.4.1 Advantages of hatchery incubation for fry introduction experiments

An important point raised at the October 2002 workshop was that hatchery fry introduction experiments would provide faster tests of competitive interactions between sockeye fry and kokanee in Skaha Lake. An added benefit is that the higher egg-to-fry survival in a hatchery would mean that less broodstock would be required from the Osoyoos stock to provide fry for Skaha Lake. To demonstrate this and to help determine the number of spawners required for different levels of fry seeding for the Analysis 5 and 6, we calculated the relative production of fry from hatchery broodstock (Table 4-3) and natural spawning (Table 4-4).

The geometric mean escapement for the observed Wells dam escapement from 1973 to 1997 is approximately 20,000. Using the life-cycle model’s base case values for the Wells-to-Osoyoos spawning ground survival rate and the sockeye female ratio (0.87 and 0.52 respectively), this level of escapement yields an average of 9000 female spawners each year from which to draw hatchery broodstock for Skaha Lake. For hatchery conditions (assuming 70% egg-to-fry survival), 100 sockeye females would produce a fry abundance per hectare that more than doubles the 60-75 kokanee fry per hectare produced from an average kokanee spawning run (Table 4-3). In comparison, under conditions of natural egg-to-fry survival, it would take 800–900 females reaching Skaha Lake and successfully spawning to produce a similar sockeye fry density in Skaha Lake (Table 4-4). Hatchery production of fry would therefore provide the opportunity for a greater range of fry stocking densities to Skaha Lake for a given impact to the Osoyoos stock (Figure 4-15).

Table 4-3: Estimated broodstock (# females) required from the Osoyoos stock for different levels of hatchery fry input (#fry/ha) to Skaha Lake. "% of expected number female in Osoyoos stock" presents the number in the far left column as a percent of the 1973-1997 geometric mean escapement to Wells dam. "Average fecundity" is the age-frequency weighted average fecundity. "% increase in total fry population" is the proportional increase in total fry (sockeye + kokanee) for given number of female sockeye relative to an average annual kokanee fry production of 75 fry/ha.

Osoyoos Females collected	% of expected number female in Osoyoos stock	Avg. fecundity	Assumed hatchery egg-to-fry survival	#Fry (x 10 ⁶)	#Fry/ha (area of Skaha Lk is 2010 Ha)	% Increase in total fry population (assuming avg. kokanee fry production of 75/ha)
100	1.1%	2768	0.7	193752	96	129%
200	2.2%	2768	0.7	387504	193	257%
300	3.3%	2768	0.7	581256	289	386%
400	4.4%	2768	0.7	775008	386	514%
500	5.5%	2768	0.7	968760	482	643%
600	6.6%	2768	0.7	1162512	578	771%
700	7.7%	2768	0.7	1356264	675	900%
800	8.8%	2768	0.7	1550016	771	1028%
900	9.9%	2768	0.7	1743768	868	1157%
1000	11.1%	2768	0.7	1937520	964	1285%

Table 4-4: Estimated broodstock (number of female spawners) required from the Osoyoos stock for different levels of natural fry input (#fry/ha) to Skaha Lake.

Females spawning in Skaha Lake	% of expected number female in Osoyoos stock	Avg. fecundity	Assumed natural egg-to-fry survival	#Fry (x 10 ⁶)	#Fry/ha (area of Skaha Lk is 2010 Ha)	% Increase in total fry population (assuming avg. kokanee fry production of 75/ha)
100	1.1%	2768	0.08	22143	11	15%
200	2.2%	2768	0.08	44286	22	29%
300	3.3%	2768	0.08	66429	33	44%
400	4.4%	2768	0.08	88572	44	59%
500	5.5%	2768	0.08	110715	55	73%
600	6.6%	2768	0.08	132859	66	88%
700	7.7%	2768	0.08	155002	77	103%
800	8.8%	2768	0.08	177145	88	118%
900	9.9%	2768	0.08	199288	99	132%
1000	11.1%	2768	0.08	221431	110	147%
1100	12.2%	2768	0.08	243574	121	162%
1200	13.3%	2768	0.08	265717	132	176%
1300	14.4%	2768	0.08	287860	143	191%
1400	15.5%	2768	0.08	310003	154	206%
1500	16.6%	2768	0.08	332146	165	220%
1600	17.7%	2768	0.08	354289	176	235%
1700	18.8%	2768	0.08	376433	187	250%
1800	19.9%	2768	0.08	398576	198	264%
1900	21.0%	2768	0.08	420719	209	279%
2000	22.1%	2768	0.08	442862	220	294%
2100	23.2%	2768	0.08	465005	231	308%
2200	24.3%	2768	0.08	487148	242	323%
2300	25.4%	2768	0.08	509291	253	338%

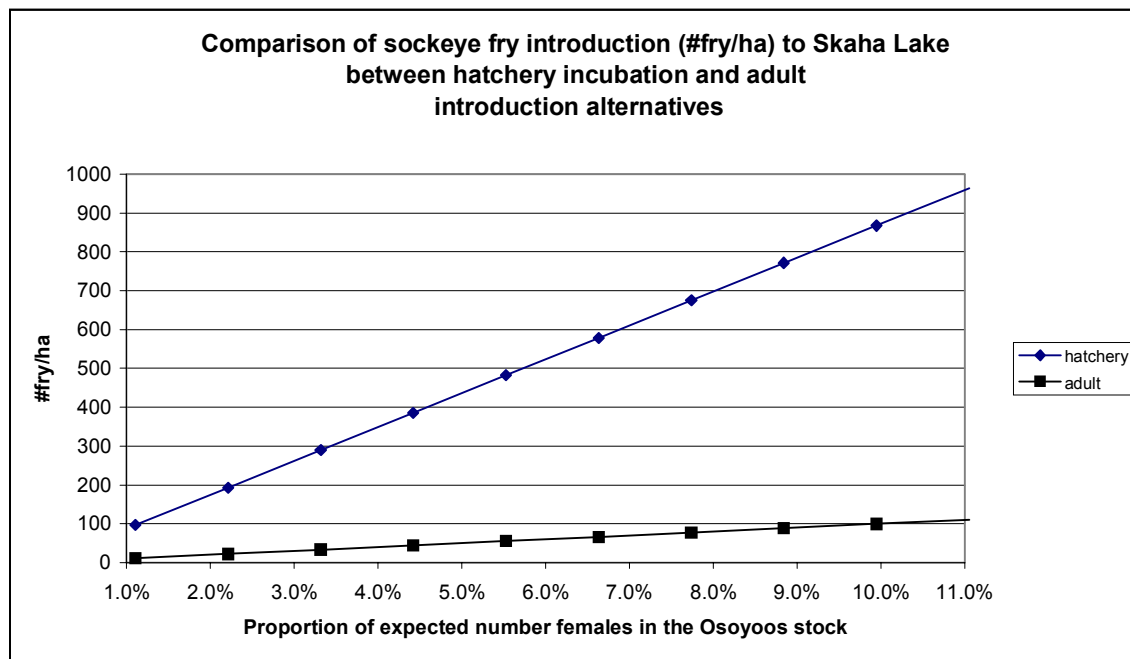


Figure 4-15: Comparison of sockeye fry introduction (#fry/ha) to Skaha Lake between hatchery incubation and adult introduction alternatives. Based on data in Tables 4-3 and 4-4.

4.4.2 Results for Analysis 5: Hatchery fry supplementation experiment

For this analysis, we started with the equilibrium Osoyoos stock settings determined in Analysis 1 and the equilibrium Skaha kokanee/mysis settings determined in Analysis 3. To simulate the existing barrier to returning Skaha adults we set the model's thermal barrier to 0 °C for both the Osoyoos and Skaha stocks.

We selected this simple experimental design:

- Five years of Before monitoring followed by five years of treatment and After monitoring.
- The treatment was 200 sockeye fry/ha added to Skaha Lake in each of the five treatment years. This required a take of approximately 385 Osoyoos spawners (females producing 200 fry/ha from Table 4-3, divided by female proportion of 0.52 to expand to total spawners required).
- The treatment was implemented in years 6 to 10 of the simulation.

We simulated this experiment without natural variability (Analysis 5a) and with natural variability added back in (Analysis 5b) to simulate process error in the “measured” indices (Figure 4-16).

Stocking sockeye fry at a rate of 200/ha over five years did not have any noticeable impact on kokanee or mysis under equilibrium conditions (Figure 4-16, left hand column of panels). Adding natural variability back in masked the downward trend in sockeye fry and spawner abundance, improved kokanee spawner abundance, and increased mysis densities (Figure 4-16, right hand column of panels). Sockeye fry-to-smolt survival over the 5-year treatment period was 0.083 and 0.093 for conditions of no variability and variability respectively. Kokanee fry-to-Age 0 survival over the 5-year treatment period was 0.41 and 0.45 for conditions of no variability and variability respectively.

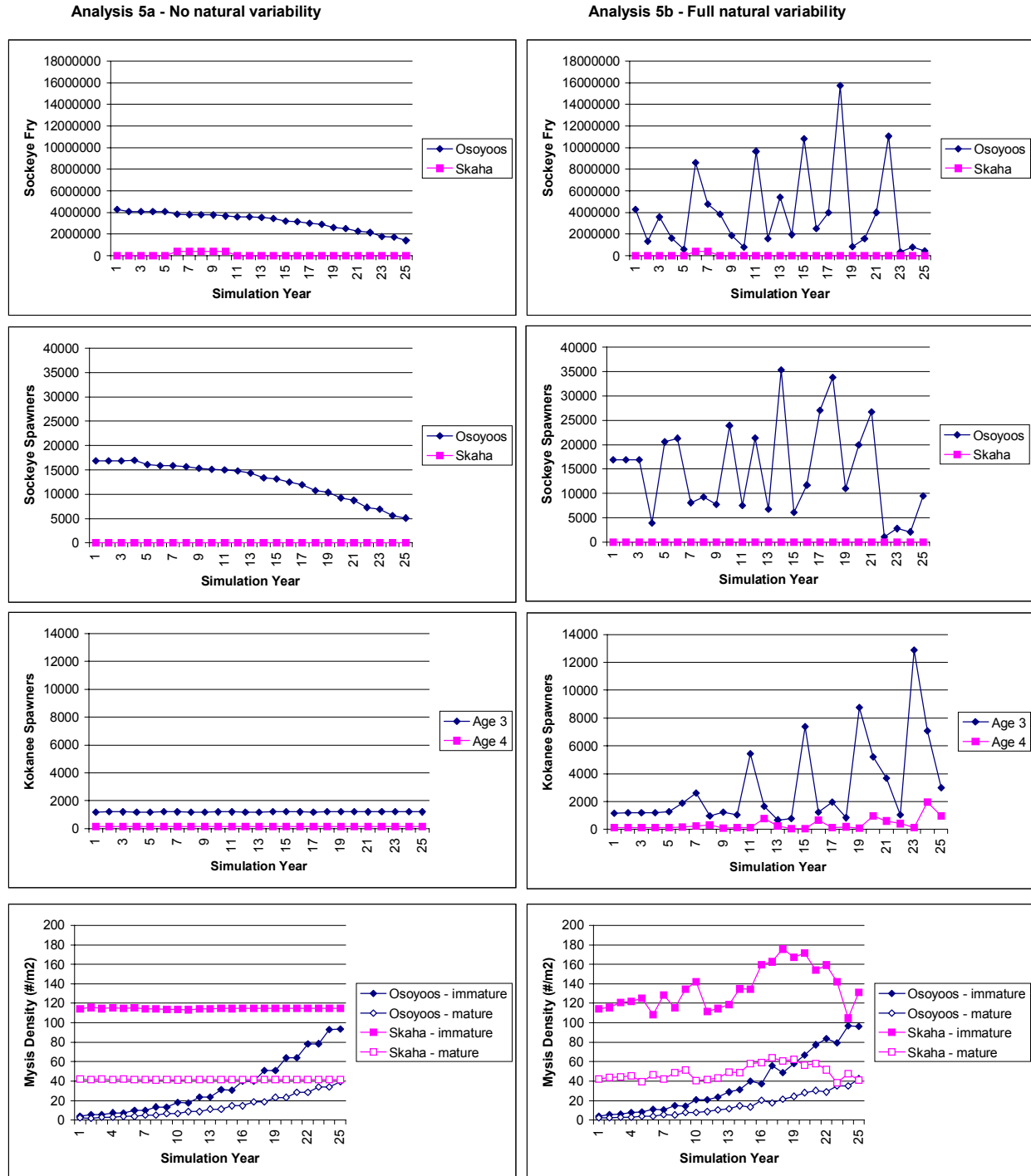


Figure 4-16: Hatchery fry supplementation experiment (Analyses 5a and 5b). The panels in this figure compare the fry supplementation impacts on sockeye fry, sockeye spawners, kokanee spawners, and mysis densities under conditions of no natural variability (left hand column of panels) and full natural variability (right hand column of panels). Sockeye fry supplementation treatment of 200 fry/ha was applied in simulation years 6-10.

4.4.3 Results for Analysis 5c: Hatchery fry supplementation experiment with mysis harvest

We modified Analysis 5a to run with an annual harvest of 50% of the mysis in Skaha Lake to explore how this might benefit sockeye and kokanee (Figure 4-17). Harvesting mysis had a beneficial effect for both kokanee fry and sockeye fry, probably by reducing the strong competitive effect mysis have on the survival rates of both (as shown in Figure 4-8). Under mysis harvest, the average sockeye fry-to-smolt survival increased from 0.083 to 0.33 over the five years of treatment (Analysis 5a compared to 5c) and increased the kokanee fry-to-Age 0 survival rate from 0.41 to 0.86 (Analysis 5a compared to Analysis 5c, Figure 4-21). This large increase in the kokanee survival rate is reflected by the steep increase in kokanee spawner abundance (Figure 4-17), right hand kokanee panel). Another, interesting results is the benefit to the Osoyoos stock that results from the improved sockeye fry-to-smolt survival in Skaha Lake. Returning Skaha spawners boost the abundance of Osoyoos spawners starting in year 9 because they cannot return to Skaha Lake (compare the sockeye spawner panels in Figure 4-17), which in turn boosts Osoyoos fry production and helps temporarily offset the steady decline of the Osoyoos stock (compare the left and right hand sockeye fry panels in Figure 4-17). Additionally, under the constant annual 50% harvest rate, Skaha mysis were driven to extinction.

These results indicate that mysis harvest could benefit Skaha kokanee and help to offset competition impacts associated with sockeye fry introduction. However, this example does account for competition between sockeye and kokanee on the spawning grounds, which should be explored through additional simulations.

Note that with natural variability, adults could only be taken in two of the five years of the treatment period (Figure 4-16, right hand sockeye fry graph).

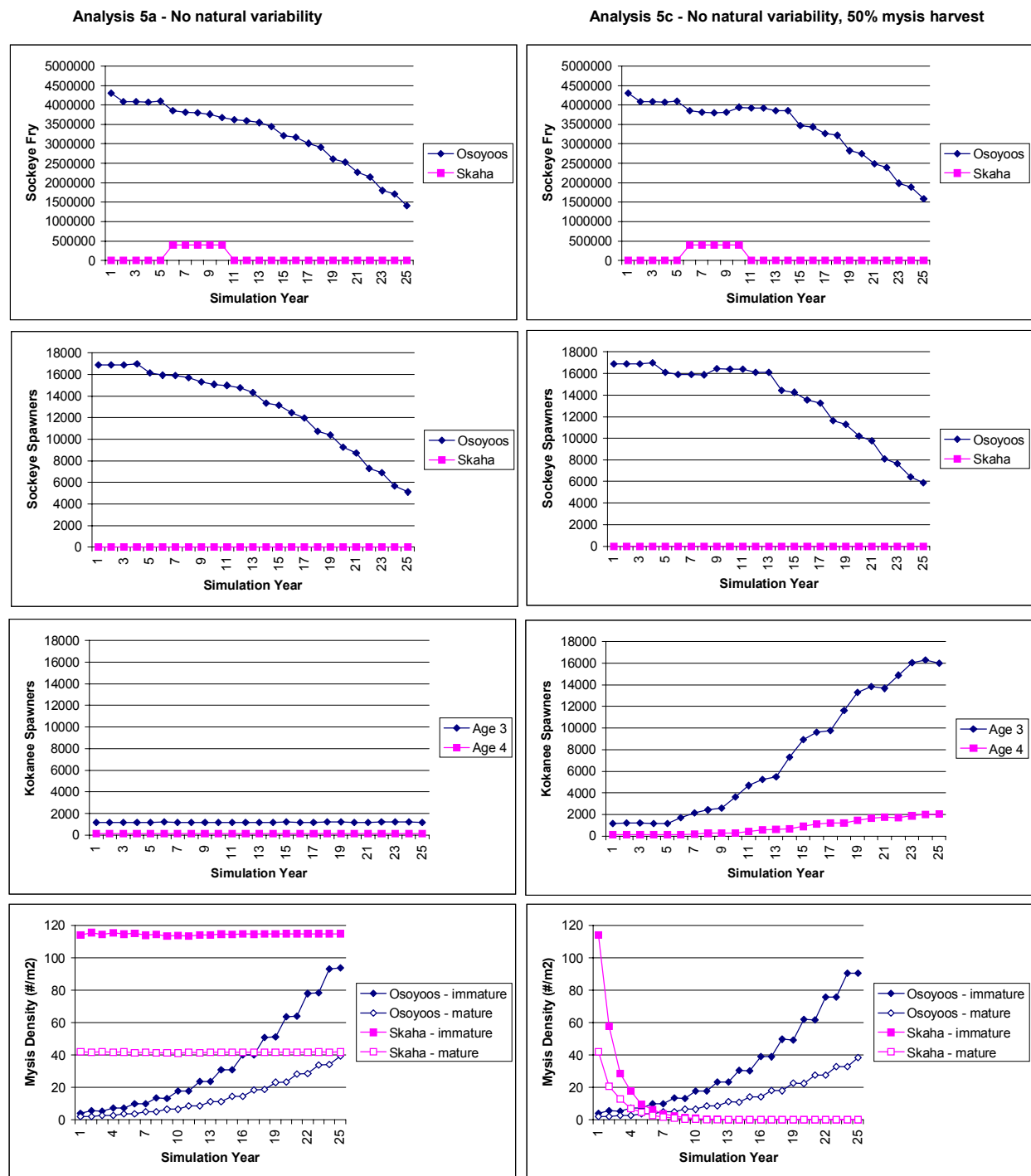


Figure 4-17: Hatchery fry supplementation experiment with harvest of mysis (Analysis 5c). The panels in this figure compare the fry supplementation impacts on sockeye fry, sockeye spawners, kokanee spawners, and mysis densities under conditions of no natural variability (left hand column of panels) and full natural variability (right hand column of panels). Sockeye fry supplementation treatment of 200 fry/ha was applied in simulation years 6-10. A 50% harvest rate was applied to mysis in Skaha Lake in every year of the simulation.

4.4.4 Results for Analysis 6: “Trap and truck” experiment

For this analysis, we started with the equilibrium Osoyoos stock settings determined in Analysis 1 and the equilibrium Skaha kokanee/mysis settings determined in Analysis 3. To maintain the existing barrier to returning Skaha adults we kept the model’s thermal barrier at 0 °C for both the Osoyoos and Skaha stocks as in Analysis 5.

We selected this simple experimental design:

- Five years of Before monitoring followed by five years of treatment and After monitoring.
- The treatment was adding enough Osoyoos spawners to add about 200 sockeye fry/ha to Skaha Lake in each of the five treatment years. This required about 3454 spawners (read number of females required from Table 4-4 and then divide by the female proportion of 0.52 to expand to total spawners required).
- The treatment was implemented in years 6 to 10 of the simulation.

We simulated this experiment without (Analysis 6a) and with (Analysis 6b) natural variability added back in (Figure 4-18).

More adults were required from the Osoyoos stock to meet the fry abundance target for this analysis than for Analysis 5 (3454 vs. 385). This requirement negatively impacted the Osoyoos stock, causing it to decline more quickly over the simulation period (compare left side of Figures 4-18 and 4-16).

Average sockeye fry-to-smolt survival over the treatment period went from 0.083 with no variability to 0.096 with variability. This result is similar to that for Analysis 5 (Figure 4-21). Average kokanee fry-to-Age 0 survival over the treatment period went from 0.41 with no variability to 0.45 with variability. This result is the same as that for Analysis 5 (Figure 4-21).

There was an impact on the kokanee fry abundance (Figure 4-21, top left panel), but this effect was small and was masked when natural variability was included (Figure 4-21, bottom left panel).

Note that with natural variability, adults could only be taken in two of the five years of the treatment period (Figure 4-18, right hand spawner graph).

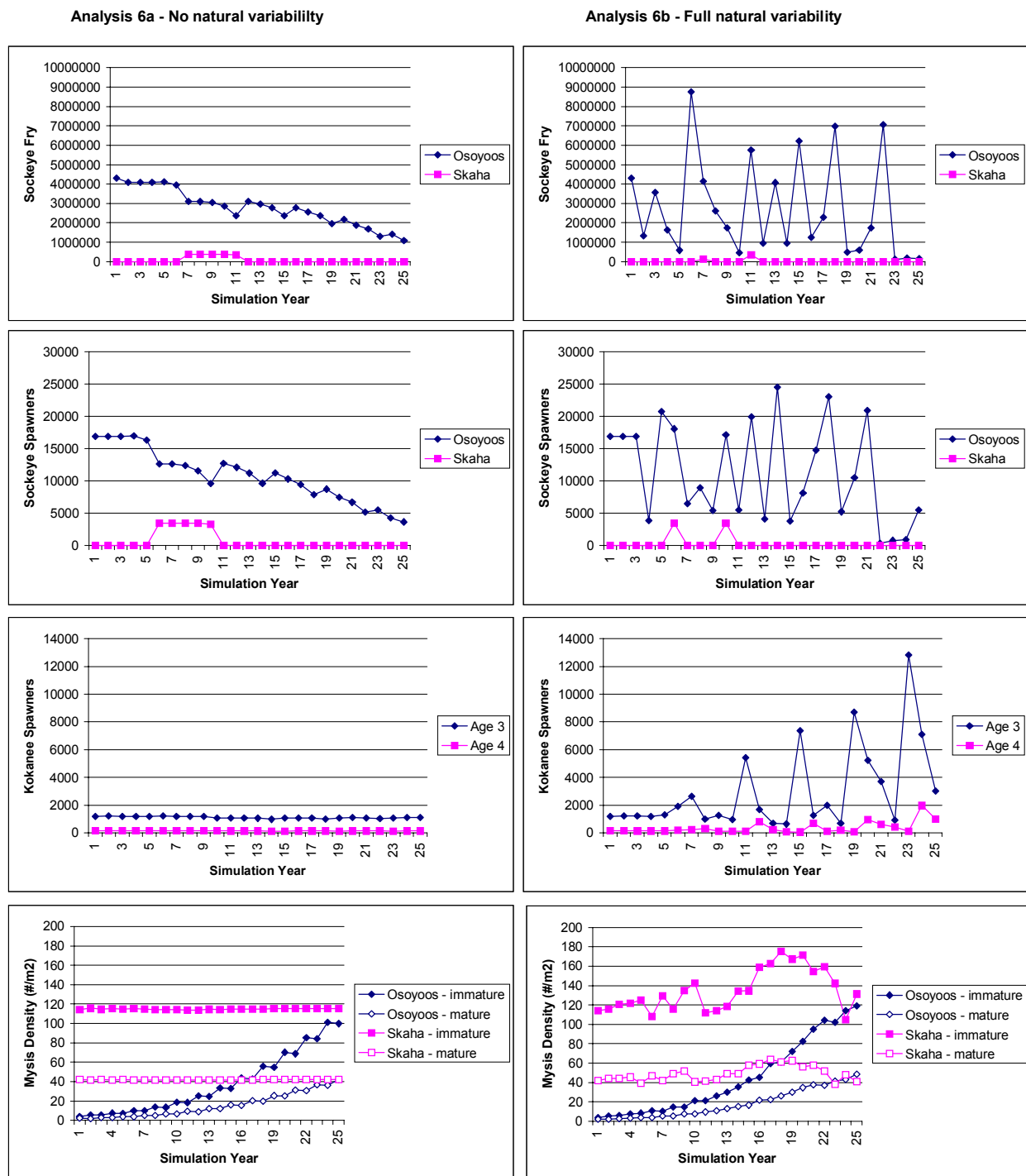


Figure 4-18: Trap and transport experiment (Analysis 6a and 6b). The panels in this figure compare the fry supplementation impacts on sockeye fry, sockeye spawners, kokanee spawners, and mysis densities under conditions of no natural variability (left hand column of panels) and full natural variability (right hand column of panels). Sockeye adults were selected from the Osoyoos stock in years 6-10 of the simulation. Enough adults were taken to stock 200 fry/ha (approximately 3454 adults).

4.4.5 Results for Analysis 7 “Remove barriers” experiment

This is the simplest of the three alternatives to simulate. We again started with the equilibrium Osoyoos stock settings determined in Analysis 1 and the equilibrium Skaha kokanee/mysis settings determined in Analysis 3. We simulated removal of the barriers to migration above Osoyoos Lake by setting the model’s thermal barrier to 15 °C for both the Osoyoos and Skaha stocks. 15 °C is the base value assumed for Skaha, but Osoyoos is set to zero under base conditions to prevent them from migrating upstream. Setting this temperature barrier higher (e.g., 25 °C) would allow more spawners to return or stray to Skaha Lake, which could be explored in an analysis subsequent to this one. At the January 14–15 workshop, Kim Hyatt noted that a default upstream temperature barrier of 21 °C is more realistic than 15 °C.

As for Analyses 5 and 6, we simulated this experiment without (Analysis 7a) and with (Analysis 7b) natural variability added back in (Figure 4-19).

The results are very similar to those for Analysis 5 (Figure 4-16). This is probably because in both cases very few spawners are “taken” from the Osoyoos stock, either deliberately as in Analysis 5, or serendipitously as conditions permit as in Analysis 7 (Figure 4-20). Therefore there is little impact on Osoyoos stock production and few sockeye fry in Skaha Lake to compete with kokanee fry and few sockeye adults to compete with kokanee adults for spawning habitat.

Average sockeye fry-to-smolt survival over the same years as the treatment period for Analyses 5 and 6 went from 0.083 with no variability to 0.092 with variability. This result is similar to those for analysis 5 and 6 (Figure 4-21). Average kokanee fry-to-Age 0 survival over this same 5-year period went from 0.41 with no variability to 0.45 with variability. This result is the same as those for Analysis 5 and 6 (Figure 4-21).

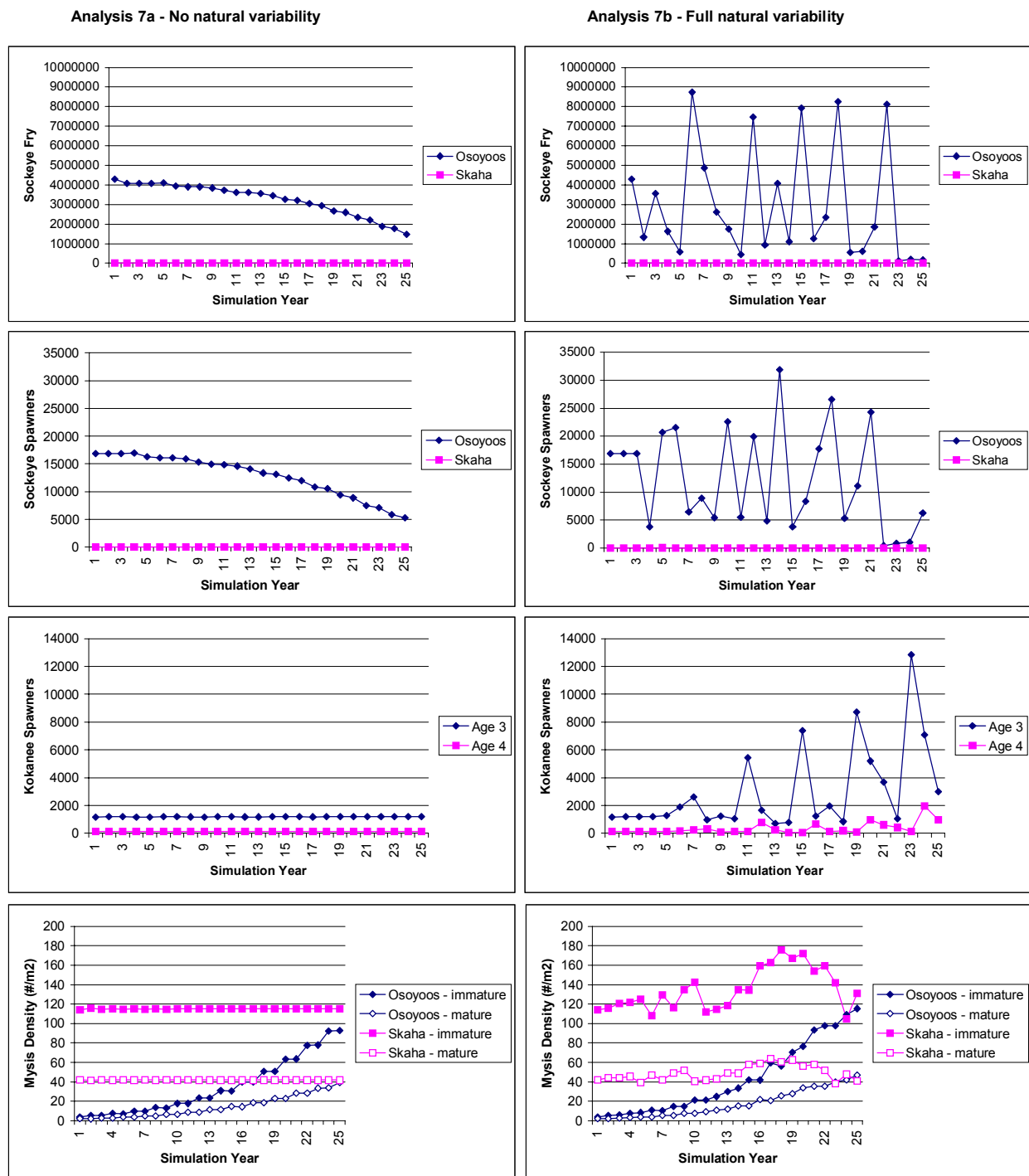


Figure 4-19: Remove barriers experiment (Analyses 7a and 7b). The panels in this figure compare the fry supplementation impacts on sockeye fry, sockeye spawners, kokanee spawners, and mysis densities under conditions of no natural variability (left hand column of panels) and full natural variability (right hand column of panels). All temperature barriers to upstream migration above Osoyoos lake were removed to simulate the removal of physical barriers.

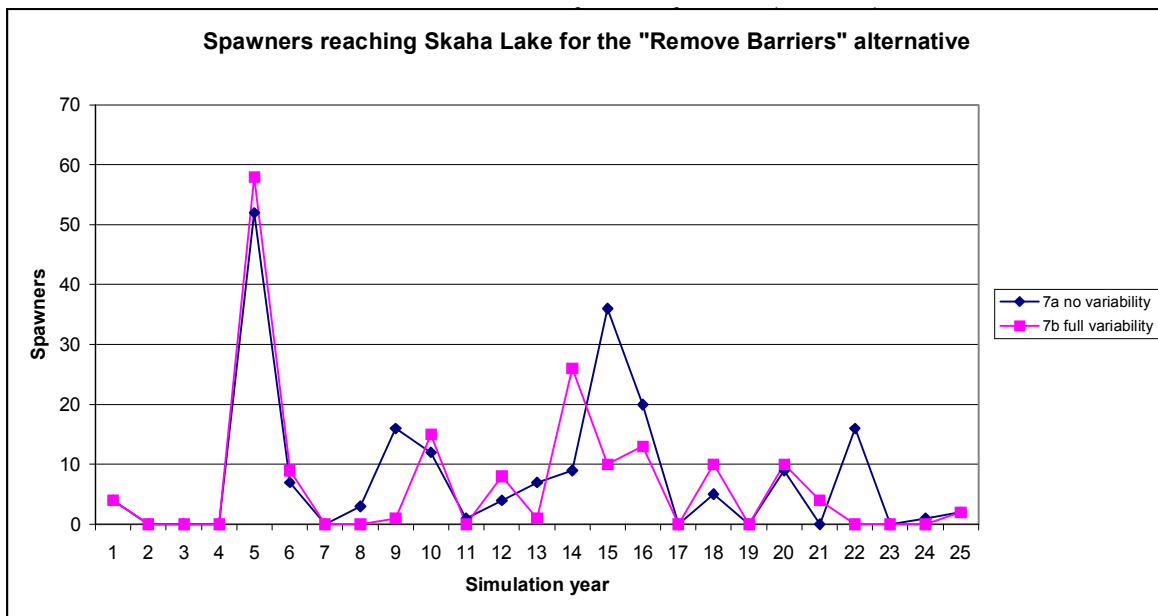


Figure 4-20: Comparison of the number of spawners reaching Skaha Lake for the “Remove Barriers” experiment (Analysis 7). “7a no variability” is analysis 7a. “Analysis 7b full variability” is analysis 7b.

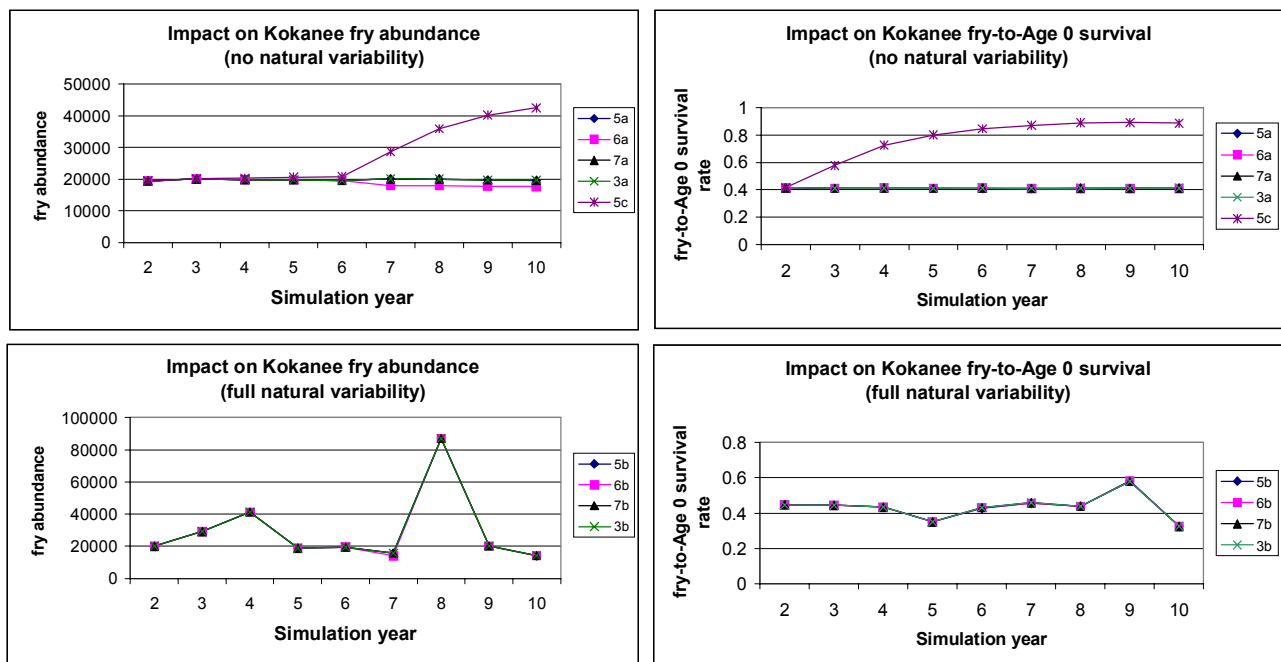


Figure 4-21: Comparison of kokanee fry-to-Age 0 survival rates and fry abundance for the experimental alternatives with and without natural variability. 3a and b are the results for Analysis 3. 5a and b are the results for the hatchery fry supplementation experiment (Analysis 5). 6a and b are the results for the trap and transport experiment (Analysis 6). 7a and b are the results for the remove barriers experiment (Analysis 7).

4.5 Statistical power analyses for example experiments

4.5.1 Introduction

The tests of significance commonly used to assess experimental results are subject to Type I and II errors in inference. A Type I error is the probability of failing to accept a true null hypothesis of no effect. An example of a Type I error would be that the sockeye re-introduction actually has no effect on kokanee, but we mistakenly conclude (due to imprecise measurements and/or natural variability) that an effect did occur, either a positive or negative effect. The acceptable magnitude of this error (α) is typically selected by the researcher, but 0.05 is often used in controlled experiments. A Type II error (β) is the probability of failing to reject a false null hypothesis, or missing a true effect. An example of a Type II error in the Skaha situation is that the sockeye re-introduction positively or negatively affected kokanee, but our measurements were unable to detect this effect. The converse of type II error ($1-\beta$) is statistical power, or the probability of detecting a true effect. While the Type II error rate is not usually set by the researcher, experiments should be designed to keep β as low as possible and therefore keep power as high as possible. This is done using *a priori* (before the experiment) statistical power analysis (e.g., Cohen 1988, Peterman 1990).

A priori power analysis involves estimating statistical power over different combinations of the four basic components of experimental design:

- the level of statistical significance (Type I error rate, or α);
- the effect size, or change, important to be able to detect;
- sample size (n); and
- sample variance (s^2).

This can help to answer important inferential and logistical questions that arise during the design of management experiments (e.g., how many years to monitor?, will adding a control system help?, what size of effect can be detected with high power?). Thus *a priori* statistical power analysis is an important tool for experimental design and evaluation.

In this section we use *a priori* power analyses to further evaluate the example sockeye introduction experiments in Section 4.4, in the context of specific questions raised during workshop discussion of monitoring requirements:

- What is the expected precision based on historical information for the selected method (e.g., range of variation for fry abundance estimates using method X)?
 - acoustic abundance estimates may have measurement error of 20-40%;
 - kokanee spawner abundance estimates, in early years may have error up to +/-100%, more recently +/-50%, plus bias associated with density, bank walks (wetted width) etc., used expansion factors based on a fence count.
- What is the desired precision (e.g., to provide statistical power of 80%)?

- Can the desired precision be achieved, given our assumptions about natural (uncontrollable) variability?
- What's the power to detect different effect sizes within a given time period?

To address these questions, we calculated the statistical power to detect the observed effects under each of the three example experiments on three indices of system performance: kokanee fry-to-Age 0 survival, kokanee fry abundance, and kokanee spawner abundance. Additionally, we explored a wider range of effect sizes, sample sizes, and variance as well as the potential benefits, in terms of statistical power, of including a control system. These analyses are provided as an example of the types of analyses that should be done prior to any large-scale experiments in order to maximise both the learning and conservation benefits of such experiments.

4.5.2 Methods

We used the OkSockeye model to simulate the trend in kokanee abundance for the example experiments presented in Section 4.1.3. The example experiments are simple balanced “Before-After” (abbreviated as “B-A”) designs with 5 consecutive years of monitoring in each period. Each experiment is run without natural variability (runs 5a, 6a, 7a, as described in Section 4.1.2) and with natural variability added back in (runs 5b, 6b, 7b). For each index, the “true” effect of treatment is the difference between the “Before” and “After” period means from the experiment run without natural variability. The size of the true effect is determined by the rules and data incorporated in the model. We estimated the natural variability (process error) around the means from the experimental run that included natural variability.

We calculated power in the context of a two-way t-test (Cohen 1988, Parnell 2002). A two-way test is appropriate since the direction of change is unknown. Power estimates would be higher if calculated for a one-way t-test. We calculated power for two levels of statistical significance ($\alpha = 0.05$ and 0.2) to explore the tradeoffs, in terms of statistical power, between learning and conservation objectives. We assumed that the minimum desired level of power ($1-\beta$) for an experiment was 0.8 (i.e. a 0.2 chance of a Type II error). We also calculated power over a range of effect sizes (changes from the Before period mean) for each index ($\pm 50\%$ for fry-to-Age 0 survival rate, $\pm 100\%$ for fry and spawner abundance) and for a range of Before and After sample sizes (2-10 years) around the base sample sizes. All power calculations were done using an Excel spreadsheet (Parnell 2002).

Kokanee spawner abundance may show the effects of interactions with sockeye several years after treatment begins, so we also calculated power assuming that the 5-year After period for spawner abundance began 4 years after treatment (i.e. a 4 –year lag due to the maturation time of kokanee).

The low level of fry introduction over three experiments (maximum of 200 fry/ha) had little impact on kokanee indices (Table 4-5), as expected from our preliminary analyses of sockeye-kokanee-mysis interactions in Section 4.2. Therefore, we explored an extreme variation of the hatchery fry supplementation experiment with an introduction of 5000 sockeye fry/ha to estimate the effect on kokanee indices under this much higher level of competition.

As mentioned above, sample variance is composed of both natural variation (process error) and measurement error. We assumed that managers could not reduce process error in a simple B-A experiment, but that they could reduce measurement error. During the workshop discussions, it was noted that acoustic estimates of fry abundance have measurement error in the range of 20-40%, while kokanee spawner abundance estimates using recent methods may have measurement error in the range of 50%

(historically, it may have been as high as 100%). To explore the impact of measurement error, we also calculated statistical power for each index by adding a measurement error of 30% to the process error.

We then explored the potential statistical advantage of adding a control system (a Before-After-Control-Impact, or BACIP design, Stewart-Oaten et al. 1986) for reducing process error (i.e. filtering out natural variation that is common to both treated and control systems) and thereby increasing statistical power. We did this by explicitly including the effect of covariance between a treatment and control system in our power calculation model. We explored the results over a wide range of correlation in spawner abundance and grounded our results using estimates of correlation in kokanee spawner abundance between Skaha Lake and several Okanagan lakes.

4.5.3 Results and discussion

Base results

There was virtually no probability of detecting the observed “true” effects of the three sockeye re-introduction experiments, because their magnitude was so small (Table 4-5). The base power results were essentially identical for all three experiments.

The largest effects were seen for the Trap and Truck experiment where the fry abundance and spawner abundance indices decreased by 8.15% and 1.45% respectively from their “Before” period means. Variance generally increased for all indices in the “After” period. The fry-to-Age 0 index had the lowest variance of the three indices (CV ranged from 0.11 to 0.22) and showed the least increase between the Before and After periods.

The kokanee fry abundance index had the highest CV (CV ranged from 0.53 to 1.73). In the Skaha simulation model, we use the standard assumption (Bradford 1995) that egg to fry survival has a lognormal distribution (mean 0.05; SD 0.5; Figure 4-22). This assumption can generate quite a large natural year-to-year variation in the egg-fry survival rate, making it difficult to detect the effects of an experimental treatment (e.g., either sockeye re-introduction or mysid removal) on kokanee fry abundance. The change in variance between the “Before” and “After” periods for fry is just a random result due to the particular sequence of random numbers that emerged in this single example simulation. If many simulations were run (say 1000), and there wasn’t a major change in kokanee abundance, then the variances in fry abundance in the “Before” and “After” periods would be similar. Other factors in the model (e.g. the time series of Total Phosphorus measurements, flow, temperatures) also affect the amount of variation in kokanee fry abundance for each period. Of course in nature you get the cards you’re dealt, which could very well result in changes in variance from the Before period to the After period.

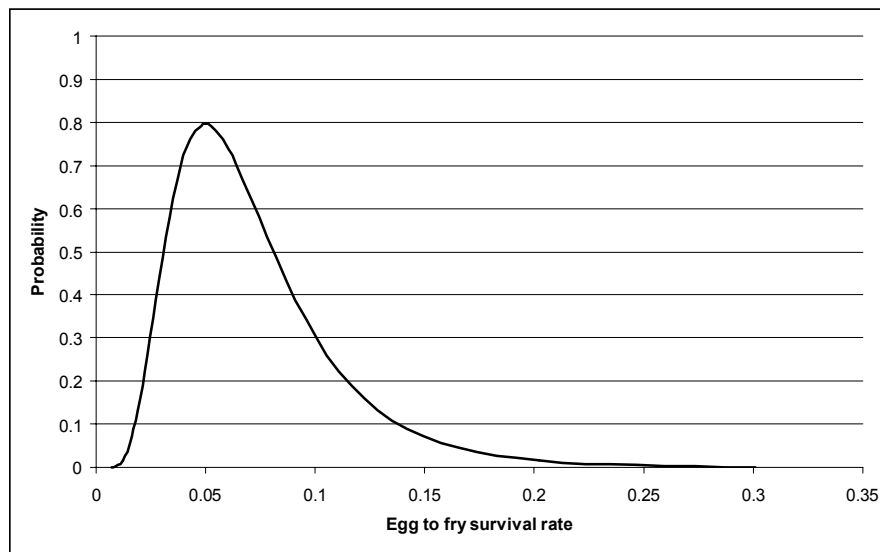


Figure 4-22: Probability distribution of kokanee egg to fry survival rates in Skaha Lake, given OkSockeye model assumptions about mean and standard deviation.

Table 4-5: Summary statistics and power results for the three example experiments. ‘n’ is the number of years in the Before and After periods. ‘SD’ is standard deviation. ‘Mean’ is the mean of the index over the Before and After periods. ‘CV’ is the coefficient of variation (SD/Mean). ‘% Change’ is the percent change from the Before period mean, or the “True” effect size. ‘Power’ is the statistical power to detect the observed ‘% Change’. Power is calculated for $\alpha = 0.05$.

Expt combo	Hatchery Fry Supp.		Trap and Truck		Remove Barriers	
	5a, 5b Before	After	6a, 6b Before	After	7a, 7b Before	After
Kokanee fry-to-Age 0 survival rate						
n	4	5	4	5	4	5
SD	0.046	0.092	0.046	0.091	0.046	0.091
Mean	0.411	0.408	0.411	0.409	0.411	0.411
CV	0.111	0.224	0.111	0.223	0.111	0.222
% Change		-0.76%		-0.60%		-0.06%
Power		0.028		0.028		0.025
Kokanee Fry Abundance						
n	4	5	4	5	4	5
SD	10397	31296	10397	31491	10398	31289
Mean	19776	19816	19776	18164	19775	19826
CV	0.53	1.58	0.53	1.73	0.53	1.58
% Change		0.21%		-8.15%		0.26%
Power		0.025		0.030		0.025
Kokanee Spawner Abundance						
n	5	5	5	5	5	5
SD	42	713	42	733	42	710
Mean	1328	1331	1328	1308	1327	1335
CV	0.03	0.54	0.03	0.56	0.03	0.53
% Change		0.23%		-1.45%		0.60%
Power		0.026		0.028		0.026

Varying Effect Size

To explore the effect of different effect sizes on statistical power, we calculated power over a range of effect sizes (changes from the “Before” period mean) using the base sample size and variance for each of the three indices of kokanee abundance (Figure 4-23). For each index, the results were essentially identical across the alternative experiments. The fry-to-Age 0 index, with the lowest range of variability, achieved a power of 0.8 for approximately a +/- 40% change in survival. The fry abundance index, with the highest range of variability, could not achieve power of 0.8 for even a +/- 100% change in abundance. The spawner abundance index, with the middle range of variability, achieved power of 0.8 for an approximate +/- 80% change in mean abundance.

It is interesting to note that the modelled range of variability for spawner abundance (CV ranges from 0.03 to 0.54) is lower than the observed range of variability for real spawner data (CVs range from 0.49 to 0.96, Table 4-6). This is a useful result for two reasons. First, it’s comforting that the modelled error is lower than the real error because the model error does not include measurement error while the real data do. Second, the difference between the model and real CVs provides a crude estimate of the measurement error on spawner abundance estimates for consideration in this analysis (about 42–46%).

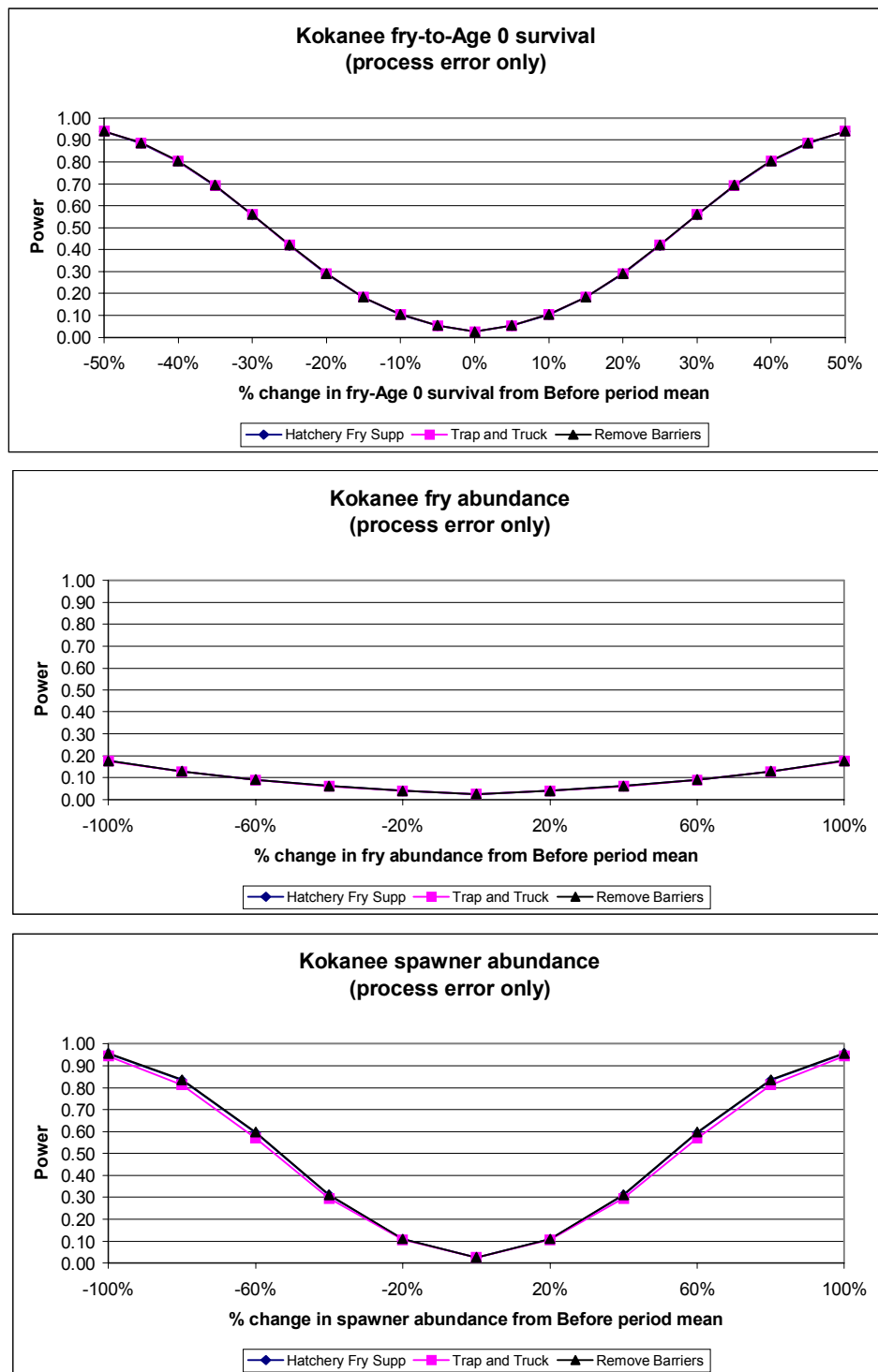


Figure 4-23: Power vs. effect size (% Change) for the three example experiments. % Change is the percent change from the Before period mean. Power is calculated using base n and SD values presented in Table 4-5, and $\alpha = 0.05$.

Varying Sample Size

Increasing sample size by increasing the length of the “Before” period, “After” period, or both periods did not appreciably increase power; power over all combinations of sample sizes ranging from 2-10 years in both the Before and After period was similar to the base results for each experiment and index.

This occurs because the degree by which increasing sample size will reduce sample variation depends in part on the relative magnitude of the variance in the Before and After periods, as well as in which period the increase in sample size takes place. For a given effect size, when total variation is much greater in the After period than the Before period, then increasing After sampling has much less impact on power than increasing Before sampling. Increasing sample sizes in the Before period did have a bigger impact on power than increasing the After sample size, but the effect was still small.

Varying the level of statistical significance

Increasing the level of statistical significance from 0.05 to 0.2 increased the level of statistical power (Figure 4-24). For example, the kokanee spawner abundance index went from being able to detect an 80% decline with a power of 0.8 to being able to detect a 55% decline with a power of 0.8. Thus, it may be worth increasing the risk of falsely detecting a change in kokanee indices when no change actually occurred (type I error or α) so as to ensure that you do detect an actual change. This would be consistent with the precautionary principles outlined in Section 2, and is commonly done for situations of this nature.⁴

We also calculated these results for a 1-tail test ($\alpha = 0.05$) to show how power increases for the test of a directional hypothesis (Figure 4-24, middle line). Such a test may be preferred from a conservation perspective where it's much more important to detect a decrease in kokanee abundance than an increase, particularly since a sockeye introduction is introducing a potential mortality factor, not removing one.

⁴ Wilson (in Appendix C of ESSA Technologies Ltd. 2002a) summarizes recent literature on the relative risks of these errors and their implications for monitoring endangered species. Lindley et al. (2000) suggest that standard methods, which control for the Type I error rate and accept the resulting Type II error rate are inappropriate when monitoring endangered species. They believe a more logical and precautionary approach is to set the Type II error rate at an acceptably small value that yields a reasonable Type I error rate. Shrader-Frechette and McCoy (1992) note that Type II error leads to possible harm or loss of benefit, respectively. In endangered species recovery activities, if a Type II error is committed, a population could be on its way to extinction before the decline is detected and preventative action is taken. Conversely, if the population is monitored after initiating recovery actions, and the population is actually increasing, a Type II error would lead to the mistaken inference that the actions are not having the desired effect, perhaps jeopardizing continuance of those actions.

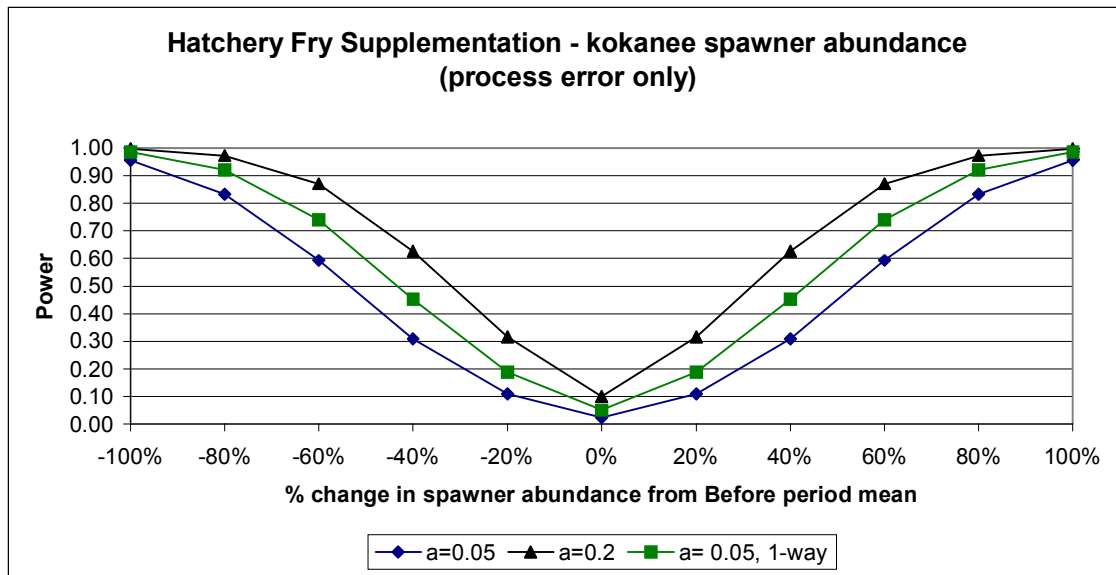


Figure 4-24: Power vs. effect size (% Change) for different levels of statistical significance ($\alpha = 0.05$ and 0.2). For comparison, power results are also presented for a 1-way t-test (middle line) at $\alpha = 0.05$. Power is calculated for the Hatchery Fry Supplementation experiment only. Calculations use base sample size (n) and variance (SD) results from Table 4-5.

Lag in Spawner Abundance

The fry-to-Age 0 survival rate and fry abundance indices will reflect impacts from the first year that treatment is initiated. However, there could be a lag-effect for the spawner abundance index depending on the hypothesised mechanism of impacts. For example, the impact to spawner abundance could begin in the first year of treatment if the number of spawners declines due to decreased growth arising from increased grazing pressure from additional fry. Alternatively, the impact may not appear until several years after treatment begins if decreased survival at fry-to-Age 0 stage from competition in year t reduces number of spawners in year $t+4$.

We estimated the “true” effect size for the spawner abundance index for the five years beginning in year 4 after treatment to capture the lagged effects of competition in the fry-to-Age 0 lifestage on spawner abundance. There was only a small change for the Hatchery Fry Supplementation experiment (%Change decreased from 0.23% to 0.12%). There was a large change for the Trap and Truck experiment (%Change decreased from -1.45% to -11.47%), but this change would have only a minimal impact on power (see Figure 4-23, power only increases to about 0.06).

Contrast with 5000 fry/ha hatchery fry supplementation experiment:

While the 5000 fry/ha supplementation rate did have a larger impact on the three indices, statistical power did not substantially increase. The %Change for fry-to-Age0 survival rate was a 12.2% decrease, for fry abundance was a 1.9% decrease, and for spawner abundance was a 4.8% decrease, which yielded power of about 0.14, 0.03, and 0.04 respectively. Power for these changes can also be approximated from Figure 4-23.

Varying sample variance/precision

Adding measurement error: While increasing precision of estimates will decrease sample variance and increase power, we assumed that process error could not be reduced for the simple Before-After design modelled here; only the measurement error component of sample variance can be controlled through improved sampling methodology. Because we ran our bases results with process error only, adding measurement error will only decrease precision and thus power.

Adding 30% measurement error, a magnitude comparable to that observed for acoustic fry abundance estimates (20–40%) and that estimated above based on differences between variance of modelled and observed spawner abundance (42-46%), reduced power relative to the base results, as expected. For example, with process error only (i.e., 0% measurement error), the fry-to-Age 0 index achieved a power of 0.8 at about a 40% change. With 30% measurement error, this index achieved a power of point 0.8 at 50% change (Figure 4-25). The results for spawner abundance could be worse given the estimate above of approximately 45% measurement error.

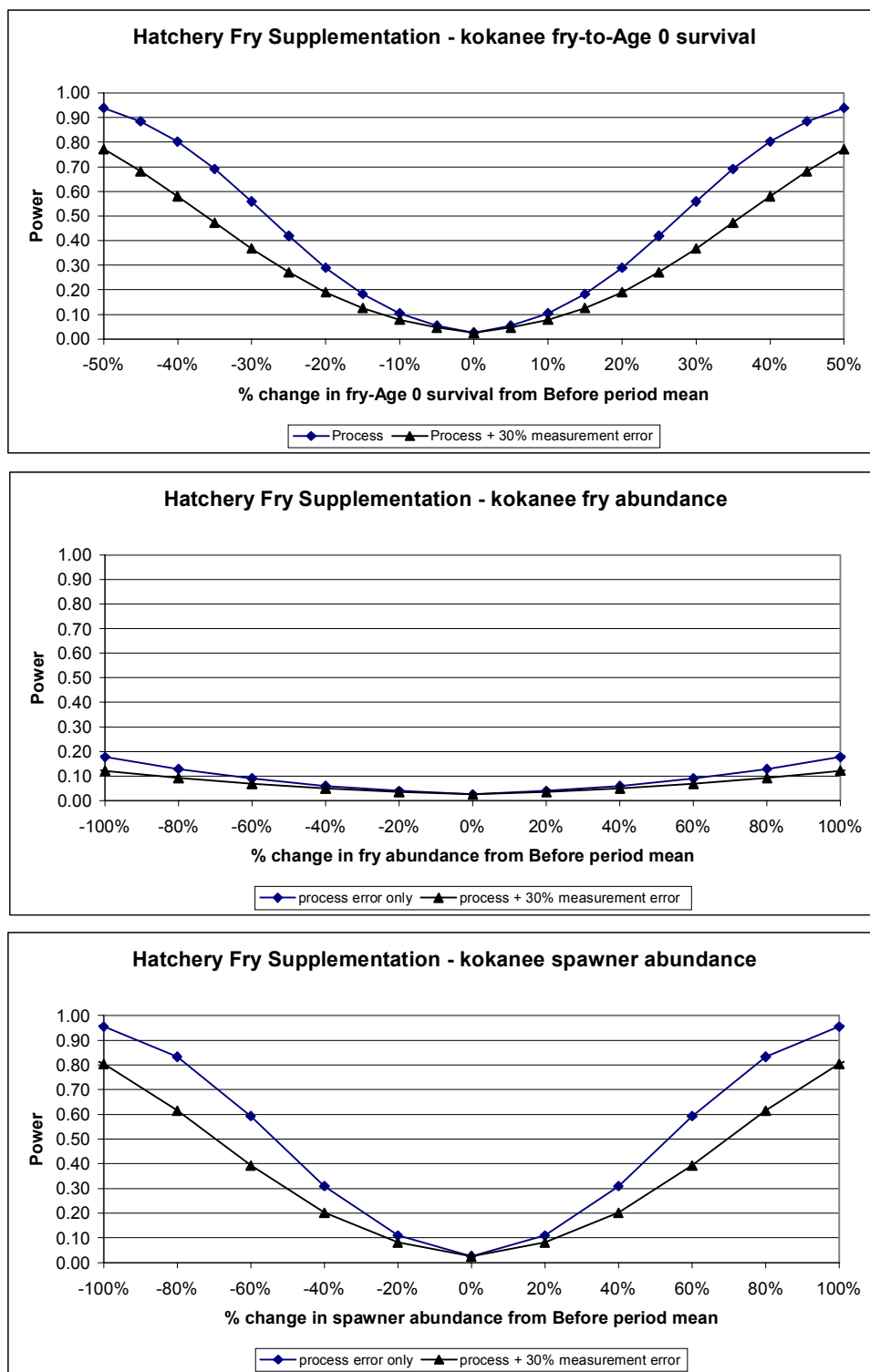


Figure 4-25: Power vs. effect size (%Change) for different levels of measurement error (0 and 30%). Power is calculated for the Hatchery Fry Supplementation experiment only. Calculations use base sample size (n) and variance (SD) results from Table 4-5 and $\alpha = 0.05$.

Benefit of including a control system for reducing process error: Managers may be able to decrease the effect of process error and increase statistical power by including a control system (e.g., in a BACIP design). We explored the effect of using control stocks to reduce process error and found that adding a single control system would only improve power if the correlation between indices was significantly greater than 0.5 (Figure 4-26). A correlation of 0.5 would produce the same variance and statistical power as the simple Before-After design. For correlations < 0.5 , power decreases because BACIP sample variance increases.

We calculated correlations between spawner abundance of Skaha kokanee and other kokanee populations in the Okanagan region (Table 4-6). The highest correlation of 0.41 occurred between Skaha Lake and Wood Lake (Table 4-7). The low correlation is not really surprising given comments by Steve Matthews that historical measurements have been very imprecise. Therefore based on historical data and sampling methods it is unlikely that including a control system will benefit inference based on spawner abundance. It would be worth exploring juvenile and adult datasets for other interior kokanee stocks to see if stronger correlations exist, or if improvements in the precision of spawning counts could be made, which would likely increase correlations. Note that the advantage of correlations between treated and control systems increases more quickly above 0.5 as effect size increases. The results in Figure 4-26 are for the base “true” effect size, which is very small (Table 4-5).

Table 4-6: Okanagan basin kokanee spawner abundance data and summary statistics. Source: Skaha, Wood, Kalamalka: B.C. Ministry of Water, Land, and Air Protection. 2002. Okanagan Kokanee Spawning Summary for 2001; Okanagan Lake: Andrusak et al. 2002 (OLAP Year 6 Report).

	Skaha	Kalamalka	Wood	Okanagan - Mission Creek	Okanagan stream + channel
1991	2200	55700	1200	11765	75522
1992	3300	26600	3200	25541	64630
1993	2400	13000	2700	9003	30653
1994	16000	39300	5700	3881	16566
1995	7300	28200	12500	6021	10304
1996	9900	24200	17000	7030	22630
1997	800	24800	8200	3422	11935
1998	10600	23300	9900	708	1735
1999	9700	9200	22300	322	1613
2000	12000	19000	12100	7357	24420
2001	11900	20000	7000	4659	38847
Var	24756182	161172727	41254727	48310103	584693667
SD	4976	12695	6423	6951	24180
Mean	7827	25755	9255	7246	27169
CV	0.64	0.49	0.69	0.96	0.89

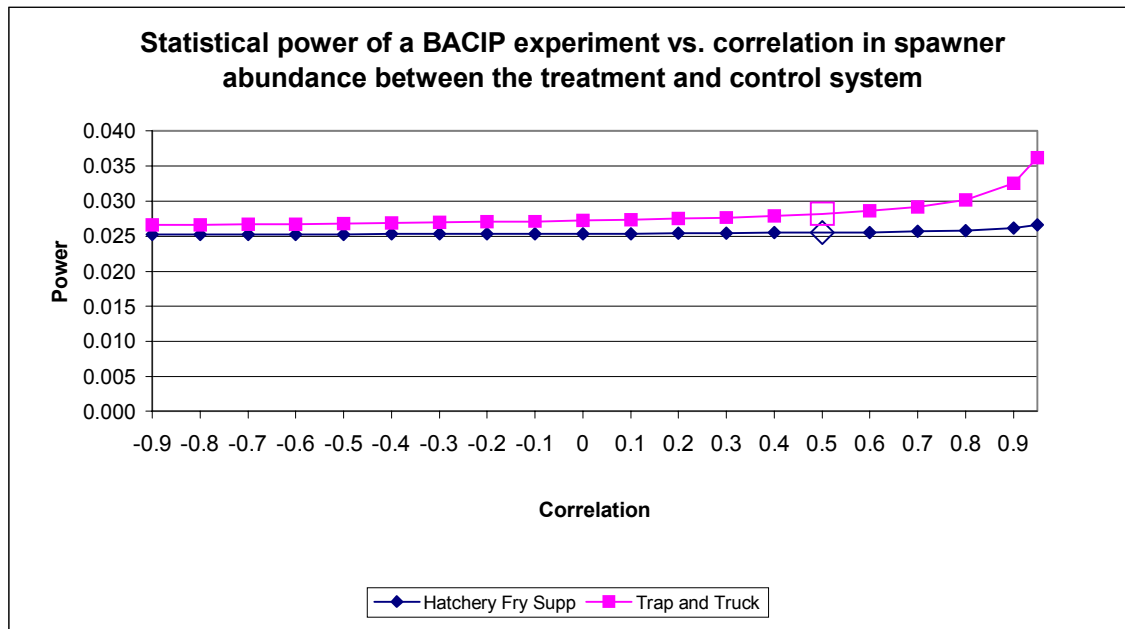


Figure 4-26: Power vs. correlation in kokanee spawner abundance between treatment and control systems. Power is calculated for the Hatchery Fry Supplementation and Trap and Truck experiments. Calculations use the base sample size (n) for spawner abundance and adjust the base variance (SD) results from Table 4-5. $\alpha = 0.05$. Open symbols indicate the base power results from Table 4-5, which occur when the correlation between systems is 0.5.

Table 4-7: Correlation of the Skaha Lake kokanee spawner abundance data with that of other Okanagan basin lakes. Data are presented in Table 4-6.

	Skaha	Kalamalka	Wood	Okanagan - Mission Creek
Kalamalka	-0.13			
Wood	0.41	-0.54		
Okanagan - Mission Creek	-0.46	0.26	-0.53	
Okanagan - stream + channel	-0.43	0.56	-0.68	0.80

5.0 Preliminary Conclusions and Recommendations

5.1 Conclusions from Literature Review

Lake-to-lake comparisons can provide insights on the ability of nerkids and mysids to co-exist, and can form the basis for hypothesising about the factors that determine whether co-existence is likely. While such comparisons are informative, however, there are many confounding factors that need to be considered when drawing conclusions. Examples include habitat alterations and loss, hatchery effects, and changes in lake productivity. Such factors make it difficult to ascribe observed declines in kokanee populations directly to mysids. Still, a more in-depth assessment and comparison of the physical and biological information in lakes with different species compositions would be a useful approach for further exploration of nerkid-mysid interactions.

5.2 Conclusions from Preliminary Analyses

1. The model is able to reproduce the observed geometric mean abundance of Osoyoos Lake sockeye (around 20,000 spawners), though to do so required a relatively high SAR of 2.6%. With mysids present, the Osoyoos population is expected to gradually decline over time.
2. Increasing the density of mysis from 6/m² to about 130/m² (the simulated mysis density in Osoyoos Lake after 25 years) reduces the equilibrium number of sockeye spawners from 20,000 to 6,000 fish.
3. Without mysids present, kokanee in Skaha Lake have an equilibrium population of about 23,000 spawners (age 3 and 4 fish); with mysids, the equilibrium population of kokanee is only 1,500.
4. The modelled fry-to-Age 0 survival rate and adult abundance of kokanee are sensitive to the assumed feeding rate.
5. For kokanee and mysis alone, kokanee performance measures are much more sensitive to uncertainty in the kokanee and mysis feeding rate than mysis.
6. Kokanee are insensitive to high levels of sockeye fry stocking. For simulations including kokanee, sockeye and mysis in combination, survival rate performance measures for all three species were insensitive to the level of fry stocking for densities that ranged from 200-1000 fry/ha.
7. For simulations including kokanee, sockeye and mysis in combination, kokanee were sensitive to mysis, but not sockeye, sockeye were sensitive to both kokanee and mysis, but most sensitive to mysis, mysis were insensitive to both sockeye or kokanee.
8. A variable SAR can improve the performance of the Osoyoos stock relative to its performance under a constant SAR.
9. Skaha Lake can support 80,000 adults kokanee for particular combinations of kokanee habitat area (habitat quantity), egg-to-fry survival rate (habitat quality), and feeding rate (competitive ability). It is believed that Skaha Lake historically supported a population greater than 80,000 adults (e.g., in the late 1960s).
10. Preliminary exploration of the conditions necessary to establish a sockeye stock in Skaha Lake showed that it required a combination of actions including the removal of barriers to upstream migration, the concurrent harvest of mysis in both Osoyoos and Skaha Lake, and a program to trap adults on the Osoyoos spawning grounds and transport them to Skaha Lake.

5.3 Conclusions from Experimental Analyses

1. Hatchery fry supplementation experiment: There was no impact to kokanee or mysis for sockeye fry stocking densities of 200/ha, which effectively quadrupled total fry densities (kokanee + sockeye fry). This is consistent with the results of the preliminary analyses.
2. Hatchery fry supplementation plus mysis harvest: Harvesting mysis in combination with fry supplementation is beneficial for kokanee and sockeye by reducing the strong negative impact mysis competition has on their fry-to-Age 0 and fry-to-smolt survival rates. This allowed the kokanee population to increase and substantially benefited the Osoyoos stock by supplementing it with returning Skaha spawners that could not move upstream to Skaha Lake. The subsequent increase in Osoyoos fry production helped offset the steady decline of the Osoyoos stock over the simulation, more than compensating for earlier broodstock removal.
3. Trap and transport experiment: More adults were required from the Osoyoos stock to meet the fry stocking target for this analysis than for the hatchery fry supplementation analysis (3454 vs. 385). This caused the Osoyoos stock to decline more quickly over the simulation period than under hatchery fry supplementation. There was also small decrease in kokanee fry abundance over the treatment period, which may have been due to competition between sockeye and kokanee for spawning habitat.
4. Remove barriers experiment: Results for this analysis were very similar to those for the hatchery fry supplementation experiment. This is probably because in both cases very few spawners were removed from the Osoyoos stock, either deliberately for hatchery broodstock, or by migration to Skaha Lake as conditions permitted.

These results suggests that mysis harvest in combination with hatchery fry supplementation would benefit the Skaha kokanee population, offset sockeye competition impacts, and also benefit the Osoyoos stock. Note that these results do not account for competition between sockeye and kokanee on the spawning grounds (see point 3), which should be explored through additional simulations.

5.4 Conclusions from Power Analyses

Based on the results of our example statistical power analyses, we conclude that:

1. The simple “Before-After” designs we have explored thus far yield statistical power of much less than the commonly applied standard of 0.8. Increasing the experimental period (up to a total of 20 years) cannot rectify this due to the small “true” impact and the asymmetry of the variance in the “Before” and “After” periods. Similar analyses should be done for other, more complicated experiments (e.g., designs that create more temporal contrasts in effects by alternating between different treatments). These example power analyses need to be supplemented by more thorough analyses that simulate the experimental re-introduction many times, to reflect the possible range of natural variation. That would give a more accurate estimate of statistical power.
2. Increasing the level of statistical significance (alpha) will increase power, but will also increase the potential for falsely detecting an effect. The relative costs of falsely detecting a non-existent effect (high alpha, high power) and failing to detect a real effect (low alpha, low power) must be considered when setting alpha levels. The first case is like having a smoke detector that occasionally goes off for no reason; the second case is like having a smoke detector not go off during a real fire.
3. Because we calculated the base results without measurement error (maximum precision), these example estimates of statistical power are likely overestimates. This means that even if monitoring

methods were improved and measurement error decreased (increased precision), it is unlikely that statistical power would attain the 0.8 level. Therefore, if a large-scale lake sockeye re-introduction experiment is to be pursued, it is crucial that managers explore ways to reduce both measurement and process error. While one can't actually reduce the process error of raw indices (it's *natural* variation), one can 'filter it out' with an adequate (i.e. well correlated) control system, and/or by explicitly modelling relationships between driving factors and indices (e.g., density dependent egg-to-fry survival).

4. While the low level of correlation in spawner abundance between Skaha Lake and other Okanagan lakes found here suggests no statistical benefit from including a control lake, kokanee spawner abundance estimates for these systems are highly uncertain. Therefore, it may be worth exploring further the degree to which kokanee spawner abundance is correlated between systems by both looking over a wider range of lakes and also modelling in detail the way that process and measurement error enter into abundance estimates. With more precise measurement methods, it may well be possible to attain correlations greater than 0.5. Additionally, covariation in kokanee survival rates and fry abundance should be evaluated, especially since the kokanee fry-to-Age 0 index had the lower variation of the three explored in this analysis. Finally, while a control lake may not help from a statistical perspective, it can support subjective interpretation of observed changes by controlling for possible confounding from other factors (e.g., unusually dry conditions everywhere that reduce kokanee survival rates and unfortunately coincide with the sockeye re-introduction experiment).
5. Our analysis also suggests that it may be worth evaluating the costs and benefits of pursuing a large-scale experiment relative to directing research efforts on interactions between kokanee, sockeye, and mysis towards smaller scale experiments, where it is possible to exert greater control over variance and confounding (e.g., lake enclosure experiments, Budy et al. 1998). Such experiments, however, also create uncertainty about extrapolating those results to the larger lake system, and generally can only be run for a single season.
6. In general, these example analyses suggest that a well-developed statistical design is needed to ensure that an experimental re-introduction of sockeye salmon will satisfy both learning and conservation objectives. Part of this design will require a more comprehensive statistical power analyses, which would include:
 - an exploration of more complex experimental designs than the simple Before/After design shown here (e.g., an OFF-ON-OFF type design);
 - strategies for reducing process and measurement error (e.g., through alternative monitoring designs);
 - a discussion of an acceptable trade-off between alpha and statistical power;
 - a more comprehensive survey of data for other interior kokanee populations to identify potential control stocks, and an exploration of the potential for improving correlations through better monitoring;
 - an assessment of the feasibility of directed, smaller-scale experiments that could complement the experimental reintroduction; and
 - power analyses for all indices under consideration for sockeye, kokanee, and mysis.

It is worth expanding on this last bullet. Our example power analyses focused on detecting changes in kokanee, but the proper design of the sampling methodology for estimating the SAR for Skaha sockeye will require a similar analysis, which simulates the natural variability in SARs, and the optimal tradeoff between precision of SAR estimates and cost. For example, using external tags on Skaha hatchery raised fry would increase initial costs, but save money later by making the identification of returning Skaha

spawners easier and so reducing the number of spawners that need be taken for otolith analysis. A key question, then, is how many Skaha spawners need to be counted in different years to get sufficiently precise SAR estimates?

Finally, it is important to remember that different design questions need to be answered depending on the purpose of monitoring a particular index. For example, in our example hatchery experiment, estimating the sockeye fry-to-smolt survival rate is a precision question: how intensive should sampling be to produce sufficiently precise estimates of the survival rate? For kokanee fry-to-Age 0, it is an impact question: what level of sampling will allow detection of a change of a particular magnitude with high power? For other types of experiments, the questions may change. For example, when combining fry introduction with mysis harvest in a sequential experiment (e.g., before monitoring of current system, followed by sockeye fry introduction for X years, then mysis harvest and fry introduction for Y years), it also becomes important to be able to detect changes in the sockeye fry-to-smolt survival rate. Although precision and power are related (increased precision increases power) the precision sufficient for estimating survival may not be sufficient for powerful tests of hypotheses.

6.0 References

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Appendix A: Information Requests Assigned at Hypothesis Workshop in October 2002

The following list of information requests was distributed on October 22, 2002, with a request to send the information by November 15th. ✓ indicates information received by ESSA as of February 14, 2002; if no ✓ appears, the information is still outstanding; a □ indicates partial information received. High (H) priority items have been included or considered in this report.

Priority	Information Needs	Responsibility/Status
H	Estimates of juvenile sockeye densities in Osoyoos Lake	Kim
H	Estimate of Osoyoos stock SAR (from CNAT)	Kim
H	Time series of Barkley Sound SARs (to get sequential variation around mean SAR for Osoyoos)	Kim ✓
L	Other CNAT data	Kim □ (<i>version 1 only</i>)
H	Summary info on TP and fish status of coastal vs. interior lakes to illustrate how higher trophic status enables sockeye and kokanee to co-exist	Kim □ (<i>qualitative summary of data received</i>)
H	Reasonable range of assumptions for egg to fry survival in sockeye hatcheries	Kim ✓
H	Shepherd (1993) memo on Mysis in Skaha Lake	Howie ✓
H	Compile literature for synoptic survey of mysid/kokanee interactions in other systems to assess ability of KOK to sustain healthy populations in presence of mysids. (e.g., Kootenay, Arrow, Slocan, Flathead, Wood, Kalamalka, etc.)	Howie (to do preliminary synthesis) ✓
L	Okanagan Lake - time series of TP (check if already on Ken Hall CD), acoustic trawl and spawning kokanee #s from WLAP database (for exploratory test of limnetic interactions of SK and KOK)	Steve
L	Okanagan Lake - estimates of the area of kokanee spawning habitat for Okanagan Lake. {Howie's estimate of habitat for kokanee and sockeye: 90 km of beach spawning habitat * 2m band of suitable depths = 180,000 m ² }	Steve and Howie? □
L	Area of Okanagan Lake spawning habitat potentially available to sockeye (Cecilia Wong report) {Howie noted that required information is not in Cecilia Wong report; use above estimate for sockeye and kokanee}	Howie to send □
L	Historical habitat area in Okanagan River above Skaha Lake and potential area of restored habitat	Howie (contact Marc Gaboury @ LGL)
Baseline information for Skaha Lake for detecting impacts of reintroduction on other ecosystem components:		
H*	Any other data on mean sizes of Ages 0, 1, 2, 3, 4 KOK from recent sampling in Skaha Lake <ul style="list-style-type: none"> within year and between year variation in these sizes (i.e., coefficient of variation) 	Howie & Steve ✓
M	existing survival estimates of year classes of KOK (Eric Parkinson) + new information from any recent sampling (model used default values drawn from LLKM model). Howie confirmed that best available information is what is in LLKM model; no better estimates are available.	Howie ✓
M**	15 years of Skaha KOK spawning abundance and distribution (if possible with a rough estimate of bias and precision)	Steve ✓

Priority	Information Needs	Responsibility/Status
H	5 years of Skaha juvenile KOK density estimates from acoustic trawl (and estimate of bias and precision) <i>Only have estimates of total limnetic fish; has not yet been apportioned between species.</i>	Kim
H	5 years of Skaha mysid densities (and estimate of bias and precision) <i>Densities about 150 to 250 /m2 in mid to late summer (sub-adults + surviving adults)</i>	Kim □
M	Summary of frequency and methods of past sampling for Skaha zooplankton) (Vic Jenson; Kim since 1997) and other explanatory variables (e.g., O2 and temp)	Kim and Howie

* We already have a spreadsheet from Steve Mathews with trawl data for 1992, 38 fish (ages 0,1 and 2), Okanagan R. data for 1987 to 1992, 540 fish (ages 2 and 3), and dip net samples from Okanagan R. channels from 1996 to 2001 (just lengths and weights, no ages). Anything else?

** We have data from 1991 on.

ESSA Model development/analyses tasks (all High priority tasks have been completed):

Priority	Task
Model development (model, interface, database)	
L	flag 'back-mapped' data in database/interface (show in different colour on GUI, in-EXCEL)
L	flag parameters that need to be changed as a group
L	new temperature/migration rule, 'If time to peak spawning is \leq X days, stay where you are and spawn.'
H	run model to trap and truck fixed # of Skaha adults from Osoyoos stock, or to stock fry (i.e., simulate expt. described under re-introduction slides above). Under latter, need to prevent adult upstream migration
L	develop appropriate scaling for strength of competition across range of biomass, or trophic state {defer}
H	add array of year-specific variation around mean SAR (e.g. 1971: +1.2; 1972: 0.8...) based on Barkley Sound SARs
H	add array of fry additions for each year of experiment (e.g., year 1:0, year 2: 0; year 3:200,000; year 4:400,000)
H	compute # females required from Osoyoos Stock (i.e., $\#fry / (0.75 \text{ egg to fry survival} * \# \text{ average eggs / female})$) and subtract these females from Osoyoos stock
M	add in array of mysid harvest rates for each year of experiment (e.g., year 1: 0; year 2:0; year 3: 0; year 4: 0.5)
Model development (output): [output to EXCEL template to help people interpret results for both Osoyoos and Skaha]	
H	Show cumulative graph over time of lake total rearing capacity (TotalCap in kg/ha), with bands underneath showing actual production of SK, KOK, mysids, unallocated prodn (kg/ha)
H	Show graph over time of egg-fry survival rate (will be constant for Skaha if in hatchery), fry-smolt survival rate (show Skaha vs Osoyoos), SAR for both stocks (will be the same for now, but we might want to add a simple relationship in which mean SAR is proportional to size, which will favour Osoyoos)
H	show fry to age 0 survival for KOK
Model analyses	
H	compare base runs to runs using new SAR time-series
H	Skaha Lake: How many fry can be introduced before there is an impact to the kokanee population? (as # fry/ha), re expt design - explore different mixes of SK fry and mysid densities for the experiment, assuming current KOK densities.
M	Need to have enough fry to have measurable outputs; determine when effects occur. Need to design expt. so that output can be used to better parameterize the model...
H	Skaha: could you maintain 80,000 KOK with more & better habitat, no mysids; and then w mysids included...
L	Okanagan Lake - how many sockeye fry to impact kokanee? (back calculate to sockeye adults), compare to fry estimates based on area of potential spawning habitat.

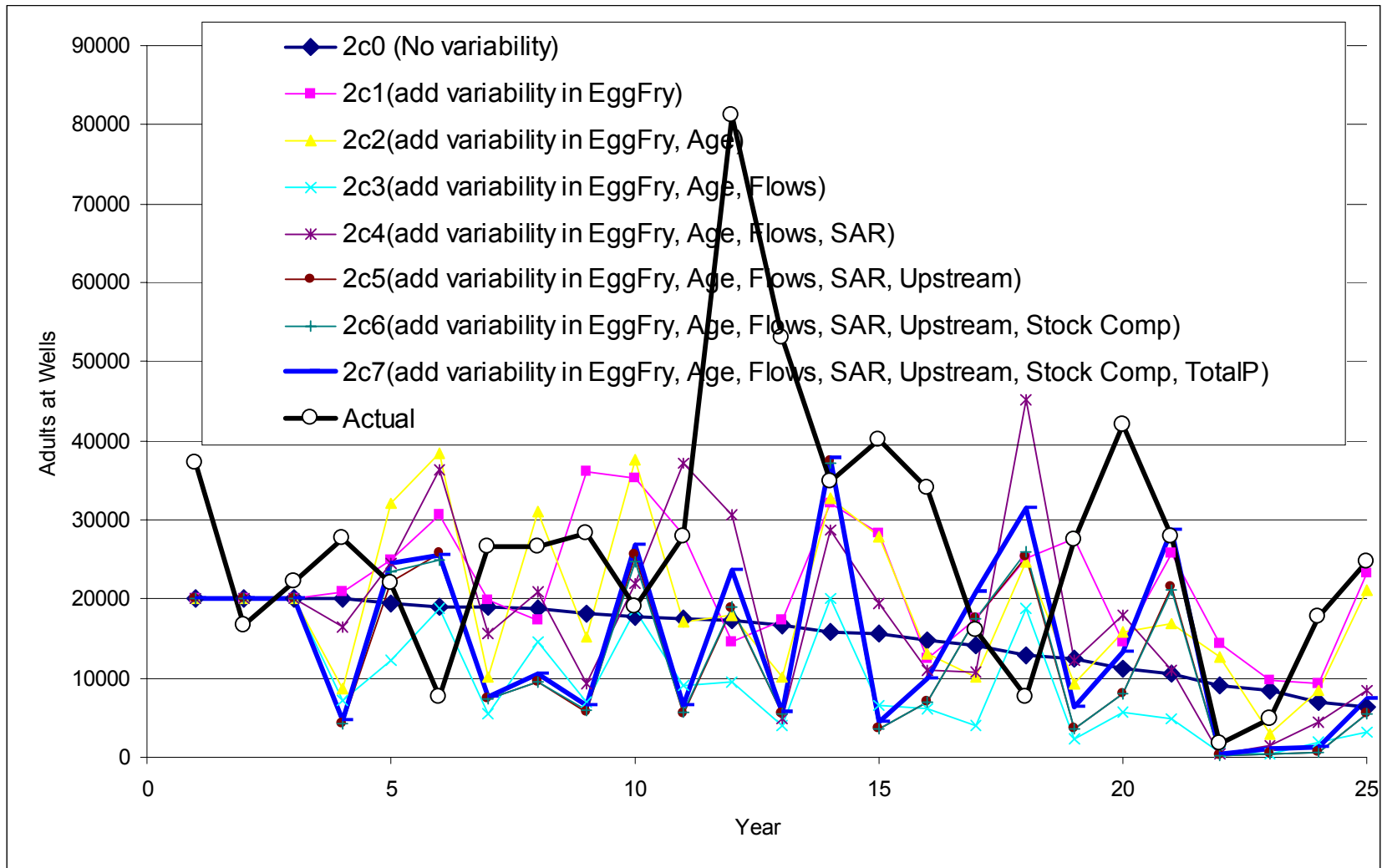
Appendix B: Detailed Model Results

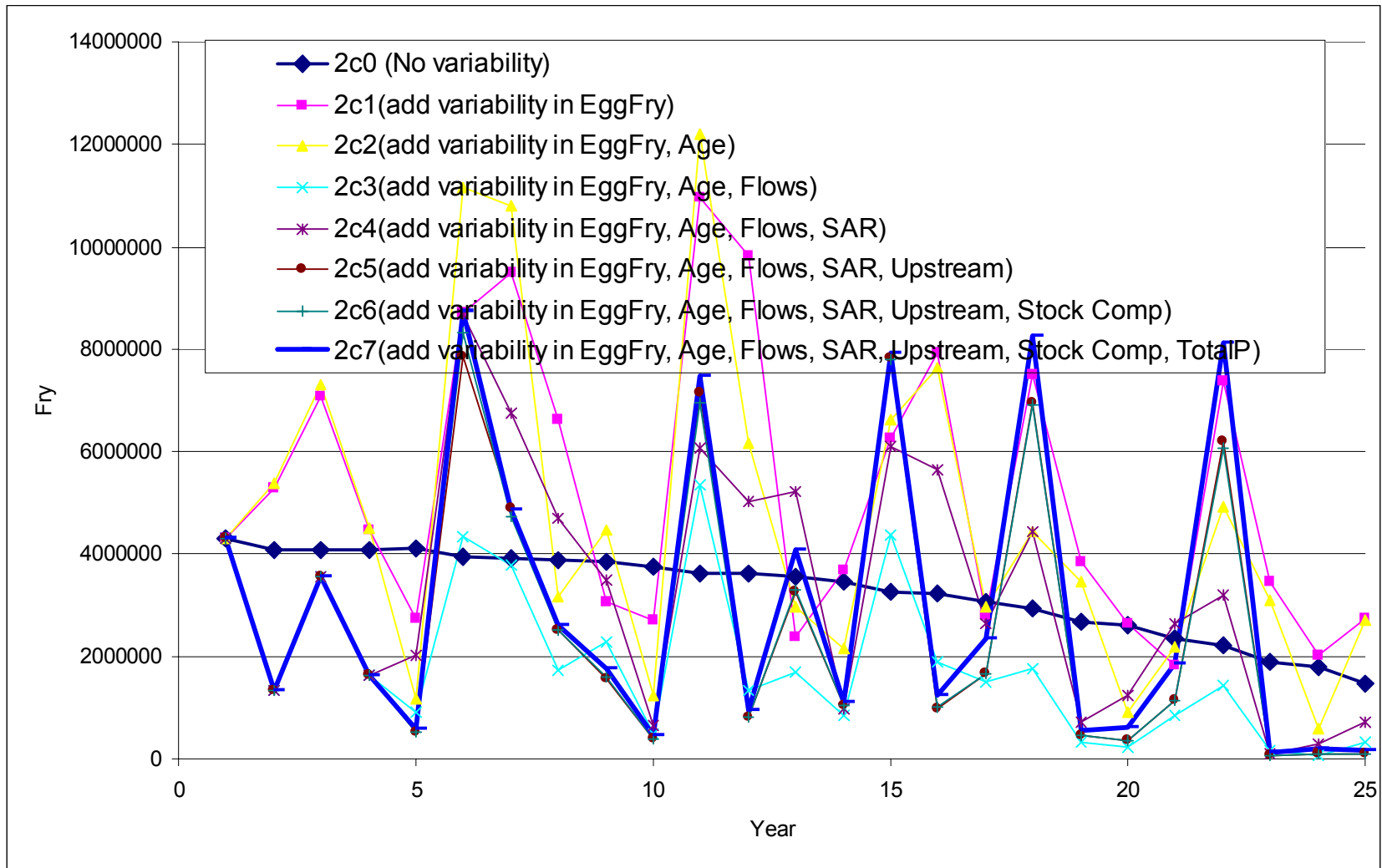
In this appendix, we provide more detailed results from the equilibrium modelling results described in *Section 4.3: Preliminary analysis*. We provide a table of model definitions, and a series of graphs showing the results.

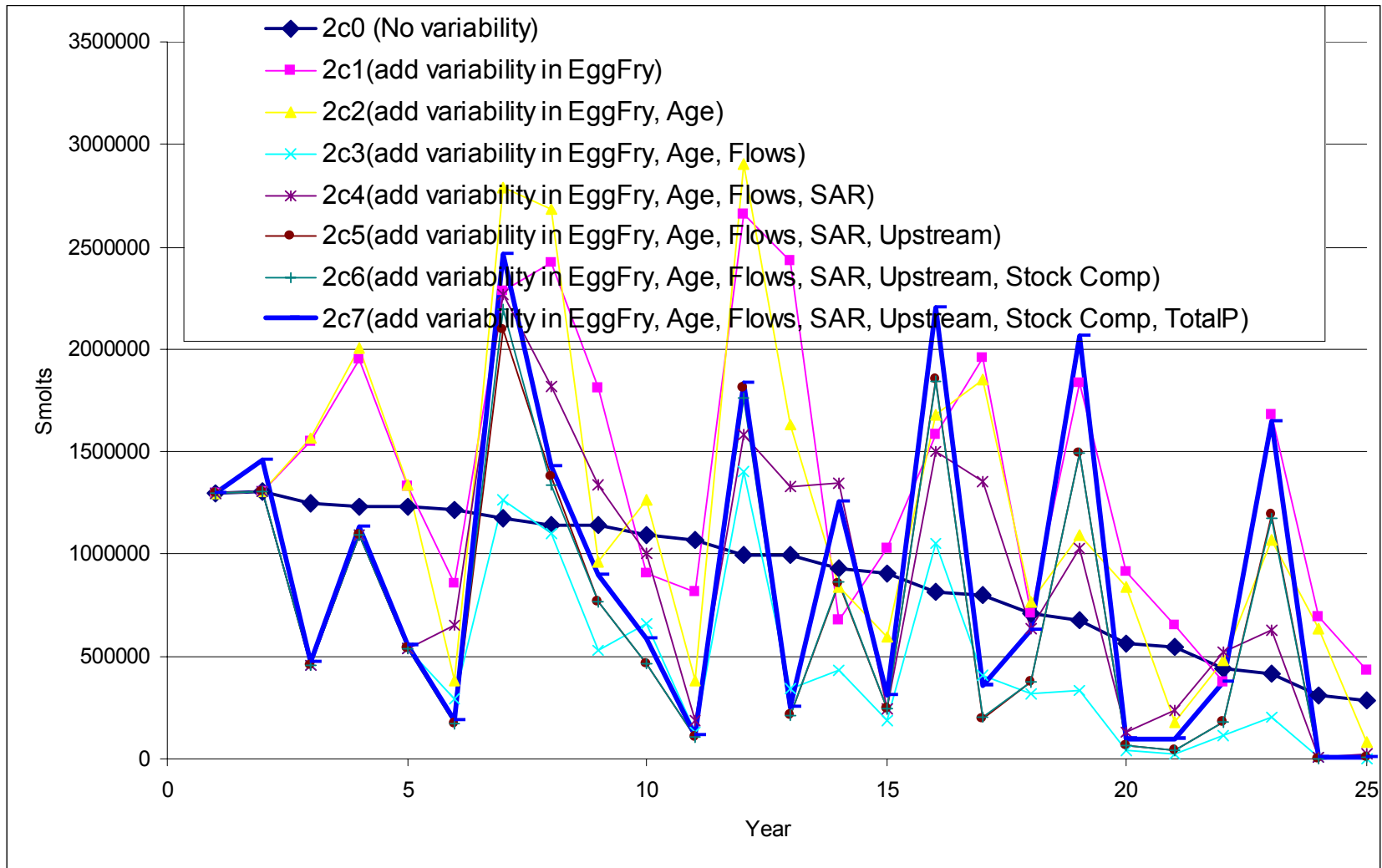
Table B-1: Summary of model runs for sockeye equilibrium analysis (Osoyoos Lake only).

Run #	Initial Mysid Density	SAR	Model Factors		Run Info
			Not variable	Variable	
1	0	2.65%		<ul style="list-style-type: none"> • Sockeye egg-fry survival rate • Sockeye age structure • Annual mean, maximum flows during spawning and incubation • SAR • Sockeye upstream survival rate • Okanagan/Wenatchee sockeye proportions • Total Phosphorus concentration 	RunID: 157; Dec. 16/02; OkSockeye(Report).mdb
2a	0	2.65%	<ul style="list-style-type: none"> • Egg-fry survival rate • Age structure • Annual mean, maximum flows during spawning and incubation • SAR • Upstream survival rate • Okanagan/Wenatchee proportions • Total Phosphorus concentration 		RunID: 159; Dec. 16/02; OkSockeye(Report).mdb
2b	6/m ²	2.65%		<ul style="list-style-type: none"> • Egg-fry survival rate • Age structure • Annual mean, maximum flows during spawning and incubation • SAR • Upstream survival rate • Okanagan/Wenatchee proportions • Total Phosphorus concentration 	RunID: 160; Dec. 16/02; OkSockeye(Report).mdb
2c-0	6/m ²	2.65%	<ul style="list-style-type: none"> • Egg-fry survival rate • Age structure • Annual mean, maximum flows during spawning and incubation • SAR • Upstream survival rate • Okanagan/Wenatchee proportions • Total Phosphorus concentration 		RunID: 176; Dec. 17/02; OkSockeye(Report).mdb

Run #	Initial Mysid Density	SAR	Model Factors		Run Info
			Not variable	Variable	
2c-1	6/m ²	2.65%	<ul style="list-style-type: none"> • Age structure • Annual mean, maximum flows during spawning and incubation • SAR • Upstream survival rate • Okanagan/Wenatchee proportions • Total Phosphorus concentration 	<ul style="list-style-type: none"> • Egg-fry survival rate 	RunID: 161; Dec. 17/02; OkSockeye(Report). mdb
2c-2	6/m ²	2.65%	<ul style="list-style-type: none"> • Annual mean, maximum flows during spawning and incubation • SAR • Upstream survival rate • Okanagan/Wenatchee proportions • Total Phosphorus concentration 	<ul style="list-style-type: none"> • Egg-fry survival rate • Age structure 	RunID: 170; Dec. 17/02; OkSockeye(Report). mdb
2c-3	6/m ²	2.65%	<ul style="list-style-type: none"> • SAR • Upstream survival rate • Okanagan/Wenatchee proportions • Total Phosphorus concentration 	<ul style="list-style-type: none"> • Egg-fry survival rate • Age structure • Annual mean, maximum flows during spawning and incubation 	RunID: 171; Dec. 17/02; OkSockeye(Report). mdb
2c-4	6/m ²	2.65%	<ul style="list-style-type: none"> • Upstream survival rate • Okanagan/Wenatchee proportions • Total Phosphorus concentration 	<ul style="list-style-type: none"> • Egg-fry survival rate • Age structure • Annual mean, maximum flows during spawning and incubation • SAR 	RunID: 172; Dec. 17/02; OkSockeye(Report). mdb
2c-5	6/m ²	2.65%	<ul style="list-style-type: none"> • Okanagan/Wenatchee proportions • Total Phosphorus concentration 	<ul style="list-style-type: none"> • Egg-fry survival rate • Age structure • Annual mean, maximum flows during spawning and incubation • SAR • Upstream survival rate 	RunID: 173; Dec. 17/02; OkSockeye(Report). mdb
2c-6	6/m ²	2.65%	<ul style="list-style-type: none"> • Total Phosphorus concentration 	<ul style="list-style-type: none"> • Egg-fry survival rate • Age structure • Annual mean, maximum flows during spawning and incubation • SAR • Upstream survival rate • Okanagan/Wenatchee proportions 	RunID: 174; Dec. 17/02; OkSockeye(Report). mdb
2c-7	6/m ²	2.65%		<ul style="list-style-type: none"> • Egg-fry survival rate • Age structure • Annual mean, maximum flows during spawning and incubation • SAR • Upstream survival rate • Okanagan/Wenatchee proportions • Total Phosphorus concentration 	RunID: 175; Dec. 17/02; OkSockeye(Report). mdb







Appendix C: OkSockeye Version History

Version	Date	Major Revisions	Comments
1.0	Jun 19, 2002	<ul style="list-style-type: none"> • Prototype; design as described in June 19th 2002 model Design Document. 	<ul style="list-style-type: none"> • Public release June 19, 2002 • demonstrated Oct 15, 2002
2.0	Dec 4, 2002	<ul style="list-style-type: none"> • Added annual SAR year effects based on Barkley Sound coho SARS • Updated water temperature functions and parameter values to be consistent with FWMT assumptions (Hyatt and Stockwell 2002) • Updated sockeye model parameters using escapement, harvest, age data in CNAT v. 1.0 (Hyatt et al. 2002) 	<ul style="list-style-type: none"> • Internal release
2.1	Dec 9, 2002	<ul style="list-style-type: none"> • Added annual fry supplementation schedule • Added annual adult supplementation schedule • Added SAR and production information to Excel Report 	<ul style="list-style-type: none"> • Internal release
2.1.1	Dec 12, 2002	<ul style="list-style-type: none"> • Corrected minor bugs related to upstream survival (only had an effect on very large sockeye escapement values) • Minor enhancements to data edit screens 	<ul style="list-style-type: none"> • Internal release
2.1.2	Dec 17, 2002	<ul style="list-style-type: none"> • Allow working with different databases • Minor enhancements to user interface (Run listbox and Save As dialog boxes) • Revise scour relationships to be consistent with Summit (2002) • Improved efficiency of initialisation 	<ul style="list-style-type: none"> • Internal release • used to generate results in Jan 8 2003 Experimental Design Report • demonstrated Jan 16, 2003
2.2	Jan 23, 2003	<ul style="list-style-type: none"> • Revised approach to computing total Okanagan + Wenatchee adult returns • Design as described in January 30 2003 Design Document 	<ul style="list-style-type: none"> • Public release Jan 30, 2003 • used to generate results in February, 2003 Experimental Design Report